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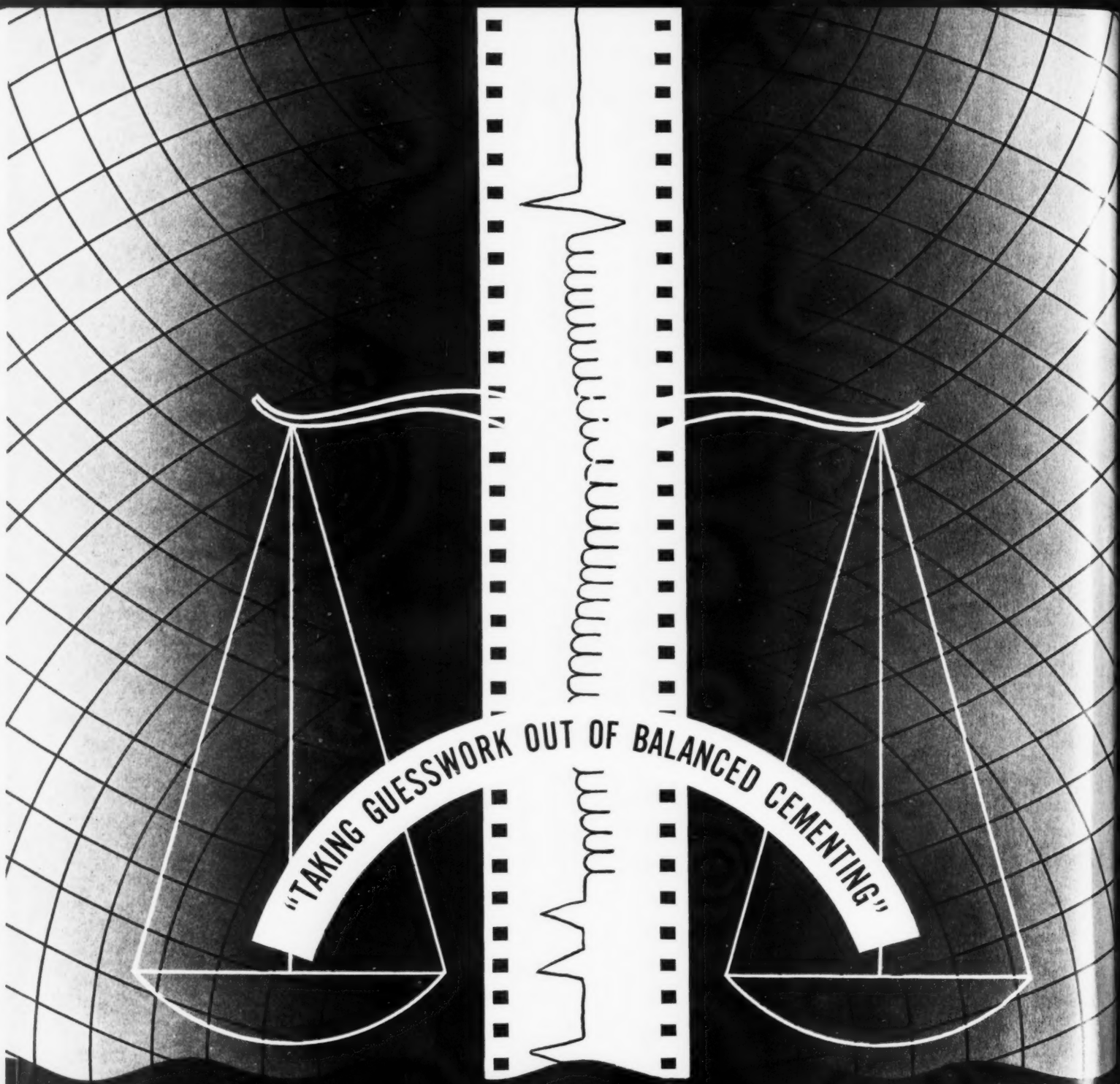

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INDUSTRY MOVES TO MEET TANKER DIVERSION

The call of the government for fifty American tankers to be assigned to the movement of oil to Britain has brought to the petroleum industry of the United States the most serious problem raised thus far by the war in Europe. The difficulty is not in providing the ships; these are being turned over as rapidly as arrangements for their new employment can be completed. It arises from the fact that most of the vessels must be withdrawn from service between Gulf and Atlantic ports. This in turn disturbs the operations of the industry at both ends of the route since all available tonnage has been employed in meeting the regular requirements of traffic between these two great producing and consuming areas.

The volume of crude and products moving by tanker between Gulf Coast and Atlantic ports averages around 1,250,000 barrels daily. Ninety-five percent of the eastward flow of oil follows the water route, occupying a fleet of some three hundred vessels. In carrying capacity they range from 5,000 to 150,000 barrels. Twenty or more of these ships are discharging cargo at one or another port every day and the loss of twenty percent of this capacity obviously must result in a serious disarrangement of the operations of the companies relinquishing the vessels.

Withdrawal of the carriers thus far requisitioned involves a rearrangement of established methods of handling crude and products that will be difficult and expensive for the oil companies affected but it does not necessarily imply an impending shortage of supplies. Substantial stocks are carried in storage at refineries and bulk terminals and certain readjustments are being made to fill the gap caused by the diversion of tankers to other routes. One immediate result will be to increase substantially the eastward movement of crude oil by pipeline, a form of transportation more costly than tanker conveyance but more efficient and less expensive than any other available means. In times past when the oil supply of the eastern seaboard states came mainly from Pennsylvania, Ohio, and Illinois numerous pipelines were built to carry crude oil from these fields to the refining centers at New York. Most of these lines have since been transformed into carriers of gasoline and other products moving westward to supply the marketing requirements of these eastern refiners. Now, in certain instances, the flow is again being reversed, and some of these lines will carry crude from west to east. While this will mean that other and more expensive methods will have to be called into use to maintain marketing operations and while some companies may lose money or possibly be forced to relinquish some of their markets it will at least provide a further means of keeping eastern refineries supplied with crude.

Between the mid-continent fields and the Mississippi some surplus pipe capacity has existed which now can be put to use for moving crude and while

Illinois presents something of a bottleneck, this can be overcome in part at least by the building of connections with Eastern trunk lines. Some saving of time and space can be effected by eliminating cross hauls and back hauls. Increase in the capacity of some lines can be obtained by looping.

Another change that is being introduced by a few large transport companies is to extend the use of barges in substitution for tankers. If the materials of construction are available barges can be turned out in from fifteen to thirty days time. While their capacity is less than that of tankers a dozen can be fabricated in the time required to construct a single tanker and they can travel safely through intercoastal waterways and along rivers and canals.

Suggestions that tank cars be employed to handle the oil formerly moved by tankers that are now withdrawn from service have come from persons unfamiliar with conditions in the transport division of the industry. While there are roundly 160,000 railway tank cars in service in the United States, eighty-five percent of these are privately owned and all are fully employed in handling current business of the owner companies. There is no reservoir of free rolling stock that can be drawn upon for long distance transportation and any cars diverted to such use would have to be taken from services in which they are urgently needed. If tank cars were available and were to be employed in moving oil from the mid-continent and Texas to the eastern states, an increase in product prices would be necessary because of the higher cost of transportation. Actually, no large increase in tank car output can be looked for in the immediate future.

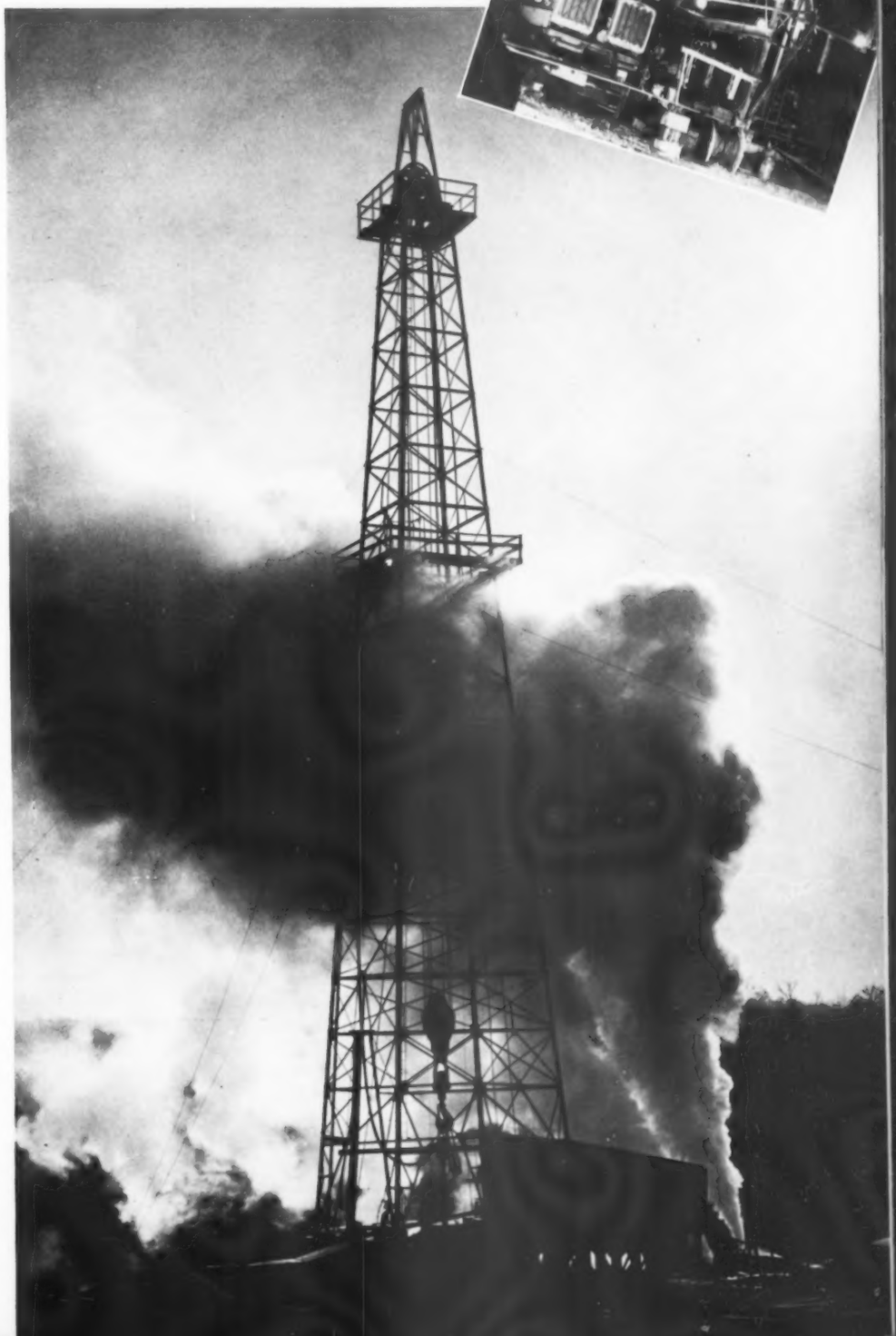
As a long range measure of relief for a shortage in tanker transportation, the building of additional pipe lines appears the most practical remedy. Carrying through a program of line construction will require time, however, and for meeting the immediate situation dependence must be placed upon readjustments in existing transport systems, reversal of the flow in certain lines and bringing into play such supplementary means of transport as are most readily available. One of the two suggestions advanced as the result of a survey made soon after the creation of the National Defense Advisory Council last year was the building of more pipe lines leading to the Atlantic seaboard. In response to this recommendation, a number of new lines have been planned or put under way by the oil companies. Various obstacles have had to be overcome, however. Two important lines designed to serve the southeastern states, which heretofore have been without such facilities and in which many training camps and military ports are located, have been held up by railway opposition which only now has been overcome.

A more disturbing aspect of the situation is the possibility that as time goes on, and if the rate of sinkings continues at its recent high rate, more and more tankers will be demanded for participation in the war effort. Such a condition might handicap the domestic service to a point when it would be no longer possible to meet the full demands of industrial and individual use in the eastern states where fully half the country's total consumption of petroleum products takes place. If the oil industry is called upon to play its part in all-out war while still satisfying domestic needs more drastic changes than any thus far considered will be necessary. Such a situation may call not merely for the pooling of tanker and pipeline equipment, but for the assignment of refineries in certain locations to the manufacture of products exclusively for military use and for the complete coordination of all facilities. The enterprise and ingenuity of American oil men will be able to solve this problem as they did in the first world war if they are permitted to act in concert and are authorized to set up from within their own ranks the authority essential to unity of action.

DRILLING SYMPOSIUM

Engineers Express Views on Drilling & Production Trends

Mechanical rigs such as the one shown on the right are replacing steam-powered rigs in numerous applications.

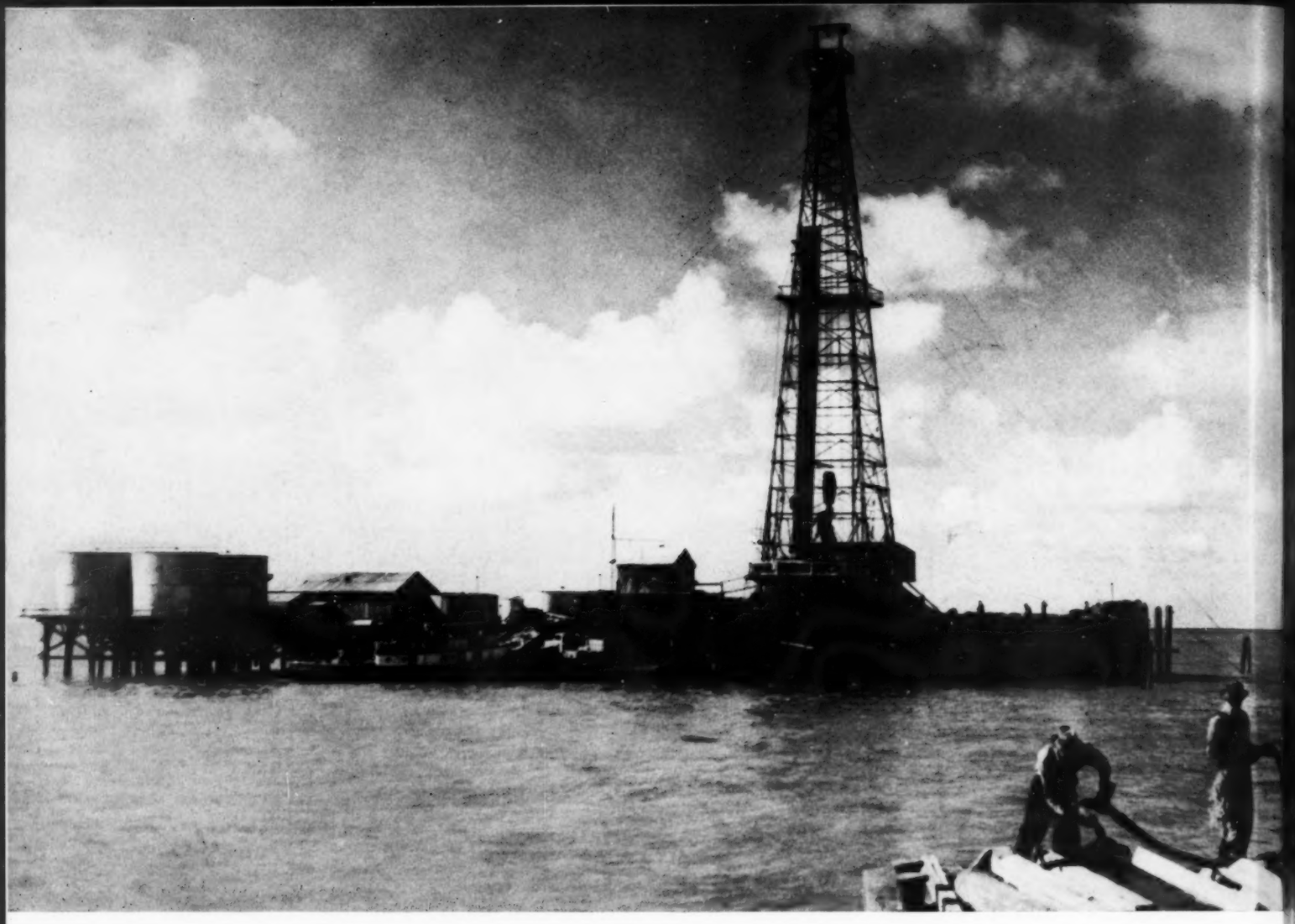


OVER the past twenty years, the prices of petroleum products have steadily declined while the cost of finding petroleum has as steadily risen. The two movements are contradictory; both cannot continue indefinitely. The search for oil is after all a commercial undertaking, albeit one in which the hazards are great and the possibility of total loss is ever present. If costs become too high and failures too frequent, the business cannot continue.

As shallow fields have come to be more and more fully drilled up, it has been necessary to go to greater depths and to attack more difficult formations to find new sources of supply. In the effort to keep such operations on a sound economic basis there is a constant struggle to speed up drilling rates, to eliminate lost time in drilling, to reduce risks and to lower unit costs. Drilling engineers and makers of drilling equipment know full well that the solution of today's problem means merely that another more difficult one must be tackled tomorrow.

No group of men is so well informed as to these constantly arising problems and the steps necessary to their solution as are those who constitute the engineering and production staffs of the oil companies. They must consider not only the physical requirements but also the economic limitations of the search for oil and they are constantly studying the problems imposed by both these factors.

The editors of WORLD PETROLEUM feel that the greatest interest and value attaches to the views of these men. With that thought in mind, they are pleased to present in the following pages the views of representative members of this group, as to present trends in drilling practice and changes in methods and equipment that will be needed to meet future conditions.



SINCE the rotary system of drilling has largely supplanted the percussion or cable tool method except for certain of the hard rock areas of the country, particularly east of the Mississippi, this discussion will be confined to the rotary method. While the problems generally associated with drilling and completions are fundamentally the same in all areas of equal depth, each individual pool has its own peculiar problems.

Most shallow fields have been exploited. Therefore, in order to meet the ever increasing demand for current consumption and to provide an adequate back-log of available reserves to meet all contingencies, it has become necessary to carry exploration to much greater depths. This, of course, means increased development costs. With an unsatisfactory price level for crude oil and its products in effect for most of the last twenty years, with the tremendous tax burden imposed on the industry and the further complication of increased costs which necessarily result from deeper drilling, the oil producer has of necessity had to devote a great amount of time, effort and money to devising and providing equipment and methods to meet conditions with which he has been confronted. As a result of this effort, substantial progress has been made in improving drilling machinery and technique and in effecting a reduction in overall drilling costs. An investigation of the records of a number of wells in the Mid-Continent area shows the distribution of expenses for drilling alone to be approximately as follows:

Item	Percent
Labor	34
Bits	20
Supplies and Repairs	19
Fuel	8
Depreciation	16.5
Moving	2.5
	100.0

It is evident from the above that drilling costs may be reduced substantially if drilling time can be further decreased. Factors influencing drilling time include hole size, speed of rotation, weight on the bit, physical properties of mud-laden fluid and the rate of circulation, as well as the use of suitable equipment in the form of mud pumps, draw-works and a rig lay-out.

We have observed a major trend in the selectivity of drilling rigs. By this I mean that the operator has now a much greater selection from which to choose. In the past the term drilling rig implied a conventional size steam rig. Although this is still partially true today, many progressive contractors and oil companies are now prone to use a drilling rig more in keeping with the job to be performed, placing special emphasis in their selection on horsepower requirements, fuel and water costs and portability. There are now available a wide range in sizes and types of rigs designed to meet optimum economic requirements. Such rigs may be of the core drill variety mounted on trucks and utilizing the truck motor through a power take-off and designed to drill small diameter holes from 100 ft. to 5,000 ft. on through the range of typical Diesel and gas engine driven mechanical rigs drilling 6¼ in. to 9⅞ in. holes to 10,000 ft. and, of course, the various size steam and Diesel electric rigs drilling even larger size holes to depths of 15,000 ft.

The heavy rotary rig of today capable of drilling to depths of 15,000 ft. is, of course, vastly superior to the first mule-driven rotary operated in Corsicana, Texas, in 1895. Nevertheless, there still remains a field for improvement in the sense of streamlining the rig and the methods of drilling to make possible the testing of formations probably as deep as 25,000 ft. It would be desirable to decrease the weight of the rotary rig, possibly through the wider use of special light high-strength alloys, together with redesign of equipment, which would affect prime movers, pumps, draw-works, and drill pipe. Further development could well be undertaken

Left, drilling in the Creole field one mile off shore from Cameron, Louisiana. Oil was discovered at a depth of one mile. Below, R. W. McIlvain of the Pure Oil Company.

Detailed Knowledge Guide to Drilling Progress

By R. W. McIlvain
Vice President, The Pure Oil Company

to provide means of reducing wear on drill pipe and tool joints, to improve drill collar connections to stand higher speeds of rotation, to develop more fully the application of fluid couplings on drives, and to continue work on the improvment of drilling bits.

In the past seven or eight years there has been a major trend toward hole size reduction, with attendant reduction in size and amount of casing used per well. Tradition, or so-called standard practices, had to be overcome in order to attain the resulting economies. Many improvements in technique and equipment have had an important bearing on the success of this major trend, combined, of course, with much better general understanding of the drilling problem.

A number of factors have contributed to the progress so far made in "slim hole" drilling. Electric logging, core analysis and side-wall coring have made it possible to evaluate with reasonable accuracy productive possibilities of horizons penetrated during the course of drilling without the necessity of resorting to conventional coring and setting casing above each prospective producing sand in order to make a test. Drill stem testing services are available to supplement other methods of testing probable producing horions. Improvement in the quality of cement and in methods of cementing have made possible the setting of one string of casing through two or more producing horizons in the same hole with reasonable assurance that the cement will be effective in protecting each porous zone and in avoiding migration of fluid from one sand to another. The development of casing perforating devices has facilitated selective testing of producing horizons through a single string of casing. In some cases where it is desirable and permissible to produce simultaneously from two or more sands in the same well and where it is desirable to shoot one or more of the producing sands, it is possible under present practices to insert in the string of casing being run a section of pipe made of easily drillable material such as Securaloy or Dow-metal. The section of pipe so inserted is spaced in the casing string at such a point that in its resting position it will be opposite the face of the sand to be tested. The application of these innovations in auxiliary devices, services and methods are of course not confined to slim hole drilling. Nevertheless, it is safe to say that without them the drilling of holes of small diameter and the avoidance of multiple casing settings, would hardly be feasible, particularly in deep holes.

There is a definite tendency toward development of highly mobile equipment. This is accomplished by reduction in weight wherever possible and by unitizing all equipment. In this latter direction, the trend is quite pronounced and it can be stated rather definitely that rotary rigs of the future at least for shallow drilling, will be self-contained units. That is, a rotary rig will consist of all equipment necessary to drill a well with mast taking the place of the customary derrick and prefabricated sub-structures replacing the common derrick base, pipe racks, and so forth. This has come about as a result of two trends; one dictated by economy and the other the tendency of many companies to let contract drilling on a turnkey basis.

While many innovations have been applied to increase capacity, applicability and efficiency of machinery, the field is too large to permit a detailed discussion in this type of treatise. Many of the improvements in drilling rigs are not obvious or revealed by visual inspection, as much of the equipment appears to be the same as has been in use for many years. There is a trend towards application of alloy steels which is very pronounced. Heat treatment of all working parts is becoming quite common. Proper balance between capacities of prime movers and operating units is being maintained, and extended to auxiliary equipment.

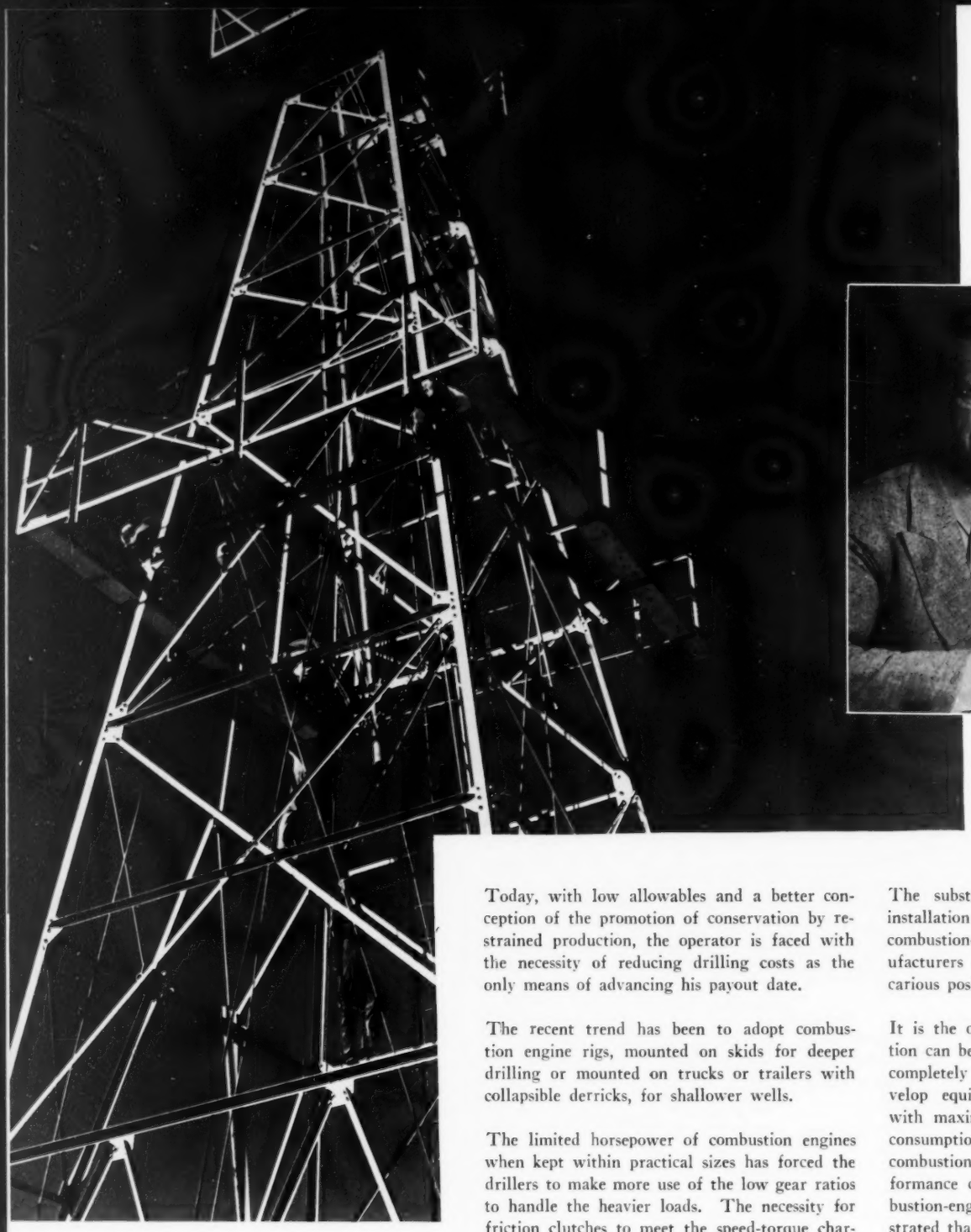
Accessibility of drilling site still remains a problem, and we must recognize difficulties encountered in moving in large machinery units in many places. Some locations are ideal, but many present difficult economic as well as physical problems. In the case of the Texas and Louisiana Gulf Coast, and certain areas of California, much drilling has been done under marine conditions. These conditions themselves represent a wide range of situations from typical swamp terrain to inland lakes, and on out into the open waters of the Gulf of Mexico or the Pacific Ocean. Many types of foundations have been prepared ranging from timber mats to piling structures, caissons, submergible steel barges and combinations of piling and floating barges. Outstanding economies have been effected with the piling derrick structure and the floating power and pipe rack barge combination in inland waters. Some structures are so expensive that recourse is had to directional drilling, and as many as ten producing wells have been drilled from one central structure.

Subsurface problems in drilling, and they are extremely numerous, have received more and more attention from the engineers. Not many years ago such problems were left almost wholly up to the drilling crews and their immediate supervisors. While the problem is complicated by many variables, and the operation often remote from the point of supervision, nevertheless, much progress is being made toward the solution of these problems, through the maintenance of systematic records and the utilization of recording type instruments. Among such studies might be cited those relating to rate of penetration as influenced by unit weight on bit, speed of rotation, type of bits and other factors. Some studies have been made on torque requirements in rotation. Records are being kept to determine the percent of total drilling time taken up with each type of operation, and similar data are being kept on drilling costs.

Drilling fluid or mud engineers are becoming more in evidence. This phase of drilling has attracted the attention of many chemical concerns and in the past five years not only has added greatly to the efficiency of ordinary drilling, but has made possible the drilling of formations which had been considered impossible of penetration. These matters essentially involve accurate control of weight, viscosity, gelling and colloidal character of the drilling mud. Rate of penetration is vitally affected by these properties, as well as the solution or at least partial solution of heaving shale, salt water flows and lost circulation problems.

Cement and cementing practice has constantly been improved. Devices are now often used to center the casing in the hole and at the same time scratch the mud sheath or filter cake of mud off the face of the hole, thereby obtaining a better bond of cement to the formation. Rotation of casing during cementing has also given encouraging results.

I cannot anticipate in the predictable future any radical changes either in equipment or technique, but rather would expect a continuation of activity in research departments of the industry and its suppliers of equipment and auxiliary services, in an ever expanding effort to improve still further practices and facilities now in use.



Building a modern derrick in California and, below, A. H. Bell, Continental Oil Co.

Prime Movers in Economic Drilling

By A. H. Bell
Vice President Continental Oil Company

FOR several years, deeper drilling and the urge for speed caused operators to demand larger and heavier equipment with the natural result that drilling costs per day have increased tremendously. In the old days an operator could pay for speed by the wide open production from his well that might be finished a few days earlier in the common pool.

Today, with low allowables and a better conception of the promotion of conservation by restrained production, the operator is faced with the necessity of reducing drilling costs as the only means of advancing his payout date.

The recent trend has been to adopt combustion engine rigs, mounted on skids for deeper drilling or mounted on trucks or trailers with collapsible derricks, for shallower wells.

The limited horsepower of combustion engines when kept within practical sizes has forced the drillers to make more use of the low gear ratios to handle the heavier loads. The necessity for friction clutches to meet the speed-torque characteristics of the combustion engine has forced them to abandon the slam-bang type of operation.

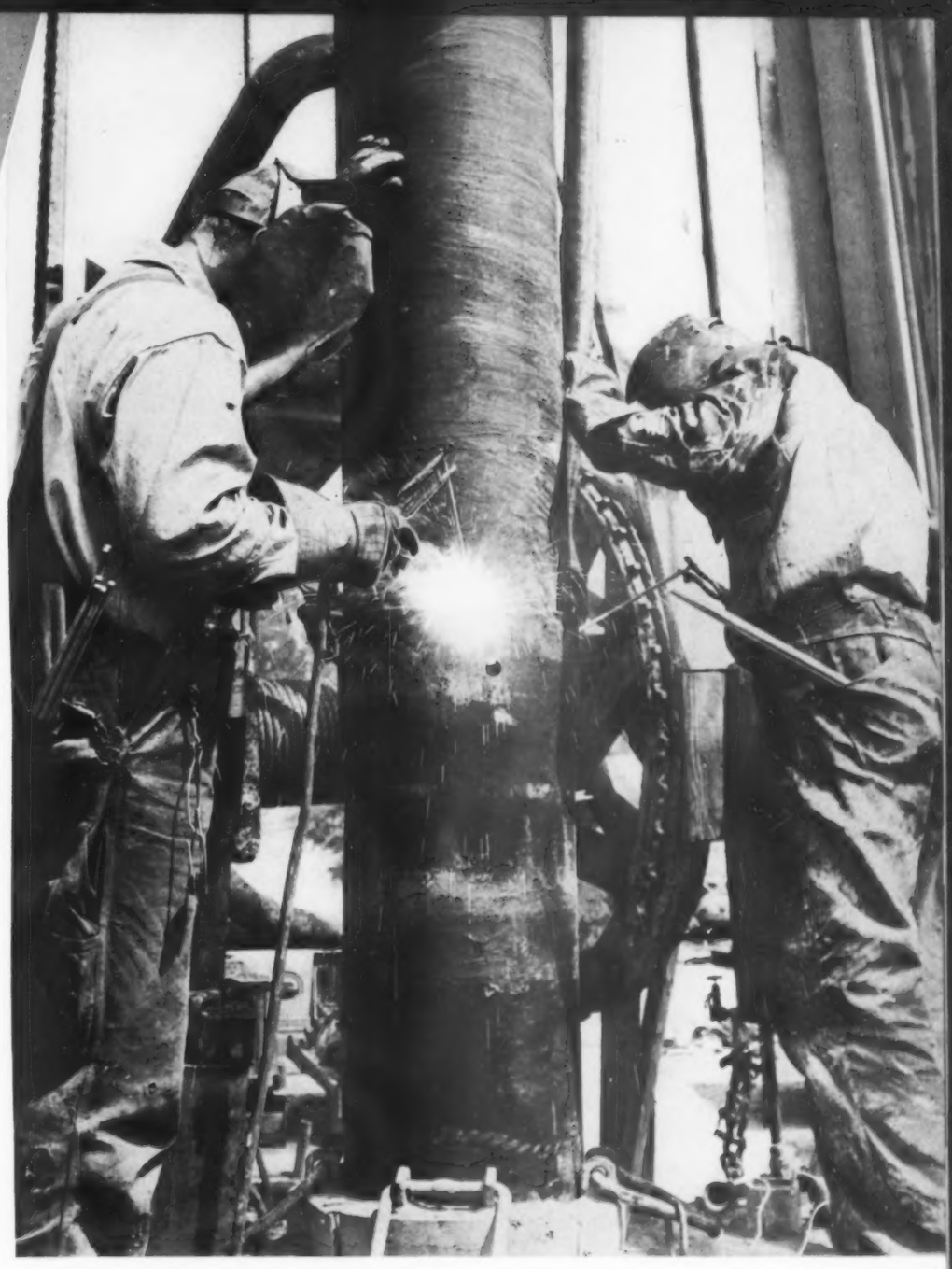
Designers of combustion engine drilling rigs have in many cases approached the problem with a fresh viewpoint because of lack of previous training with conventional steam rigs and have therefore been able to throw aside tradition and prejudice, and produce streamlined light equipment, using to advantage methods developed in the automotive industry.

Many operators think of the drilling conditions in the well as causing damage or failure of the drilling equipment, but it is actually the prime movers that cause the damage.

The substantial savings in fuel, water and installation costs that accrue from the use of combustion-engine rigs are fast putting the manufacturers of steam-driven equipment in a precarious position to defend their markets.

It is the opinion of the writer that this situation can be reversed if these manufacturers will completely revise their designing policies and develop equipment having small prime movers with maximum cut off for economy of steam consumption and horsepower equivalent to the combustion engines now in use. Recent performance comparisons between steam and combustion-engine rigs in the same field have demonstrated that many steam outfits are greatly overpowered. As horsepower is pyramided at a drilling project, the equipment cost, depreciation, and maintenance soar proportionately; the over all drilling economy does not gain in like ratio, and it may often suffer a loss.

The practice in the past has been to power steam equipment so that it can pull until something breaks. The result of this has been to build drawworks stout enough so they won't break and so on. If the steam prime mover were built in as an integral part of the pump or drawworks the manufacturer could then limit his sizes to the prime mover's capacity without fear of a larger engine being substituted which would damage the equipment.



Above, L. E. Porter, Richfield Oil Co. and right, welding surface string at the rate of 7 joints per hour in California.

Preplanning Aids Economical Drilling

By L. E. Porter

Assistant Manager Exploitation Dept.
Richfield Oil Company

DRILLING Practice: The trend of drilling practice with increased depths has been to obtain more power and sufficient strength of materials to meet these ever-increasing depths which the drill is required to reach. It has been a natural sequence that smaller-size holes have been adopted by many operators in order to reach their objective with equipment which they had rather than resort to proper engineering and strength of materials to drill the kind of program which might yield greater returns over the life of the property. It is only in recent years that most operators have begun to understand that great depths, after all, are reached only through proper observance of the power and strength of equipment and materials; and that failure to observe the critical power factor of their equipment and the safety factors of materials for these depths may result in a general breakdown of machinery accompanied by costly fishing jobs and failures. Therefore, with the adaptation of proper power factors and strength of materials, greater speeds have resulted for the size of hole drilled. When the engineering approach was given the opportunity to reach this stage of the investigation, the engineer, being an orderly sort, pointed out to the operators many time-saving means for performing their work; as a result, greater speeds have been had in drilling, and a general reduction of costs has occurred.

The biggest thing which has resulted from the application of engineering to drilling practices perhaps has been an orderly plan of development with equipment at hand or the selection of the proper equipment to perform the work confronting the operator. To obtain greater speed in drilling under safer conditions and at less cost, I feel that the industry will have to resort to;

(a) a continued application of the proper design of adequate drilling equipment for the work to be done;

(b) a continued increase of efficiency through promoting more orderly development;

(c) a continued application of practical engineering supervision for such phases as machinery design, mud control, and the proper interpretation of the underground physical forces to be overcome.

New Types of Drilling Machinery: It has been found that drilling costs have been materially reduced, in many instances, by the employment of an adequate size "spark plug" or combustion engine-driven drilling machinery. The employment of such machinery rather than the old steam-driven outfits has tended to eliminate the costs involved in setting up boilers, the purchase and maintenance of boilers; the troubles in treating boiler water; and the costs involved in transporting necessary boiler fuel and water; because the so-called "spark plug" outfits have shown a decidedly lower consumption of water and fuel than the steam methods. It appears to me that the present and future should hold as an objective the designing and production of adequate size power units to perform given jobs. When these units first came out, they suffered malpractices at the hands of the operators because many operators looked to the initial investment involved in making their selection and, as a result, inadequate equipment was generally purchased to perform the work expected of it. Such an error has now been fairly well recognized by most practical operators; but the manufacturers and design engineers must also recognize this problem and come to the assistance of these practical operators in meeting their development

problems. This means, then, that the designer and the manufacturer must fabricate the material to perform the work which the operator has to do; and a thorough exchange of ideas doubtless will prevent the operator from buying equipment too small to perform the varied work expected of it. Likewise, the designer and the manufacturer must have a thorough knowledge of the performance expected of the equipment.

Decreasing Costs and Efficiency of Exploratory Drilling by Preplanning the Actual Work to be Done: In connection with development or exploratory work, a shortening of drilling time and a saving in money can be brought about by streamlining the exploratory methods of drilling. This idea is not new as many operators are using it and have used it before. It does involve requesting the complete co-ordination of the geologist, the petroleum engineer, the drilling superintendent, and management toward the objective to be reached. About ten years ago, the electric log, the side-wall core sampler, well surveys, formation testers, etc., were talked about but little used—in fact, some of this apparatus did not even exist. Today we know something of the efficient application of such equipment (and also some of its limitations) in development work.

Adaptable Equipment for Shallow Exploratory Drilling and Remedial Work: This combines two subjects involving slightly different equipment to perform the work of each; nevertheless, the principle in both is the same, namely, the employment of proper size drilling and production masts which can be moved onto the job with the least possible expense and yet have adequate height and sufficient strength to perform the work. There are many portable masts on the market, but their employment has been retarded because of several factors: high costs of equipment, inadequate size, cumbersome methods of employing such equipment in the field, and the lack of understanding between the operators and the manufacturers and designers in the selection and employment of such equipment.

In case of development work, there are many areas where the holes to be drilled will be less than 5,000 ft. in depth. If the surface investment can be kept at a minimum through the employment of proper portable unitized derricks and rotary equipment, it will do much to minimize the cost of exploration.

In old fields, there are many holes which can have successful remedial work done on them provided the cost of such work is not excessive. It may consist of deepening the wells slightly below their present depths, plugging back to sharp shoot for upper zones, or the actual repair of casing or liners within the present zones. In some fields of Southern California, it costs between $4,500 and $7,500 to replace or repair the derrick and foundation, install necessary gas and water lines, and get the location ready for the actual work to be done. It is readily seen, then, that if a satisfactory portable mast is made available, the old derrick can be pulled down, its foundation eliminated, and the portable equipment moved in to perform the work. For this phase of the work, the lighter exploratory equipment mentioned above can be employed.

In either of the above recommendations, the problem resolves itself for any given operator, into an actual study of wells or possibilities for which such portable equipment can be employed. It then becomes one of economic calculation to substantiate the purchase of such equipment. Nevertheless, the entire problem in our California field activities to date has been the fact that the designers and manufacturers of such portable equipment have not taken into consideration the actual field problems to be coped with by the operators. For example, in Southern California today, there are not over one or two makes of a portable derrick that will begin to meet the operator's general well problems in Southern California fields; and even such equipment, at its best, is cumbersome and requires too much space to set up. Thus, the industry does have a definite call for the design and manufacture of equipment of this type. When these problems are solved, it will constitute efficiency and economy to all operators. However, to minimize the cost of design and production, the operators must also yield to the point of allowing the manufacturers the privilege of commercial standardization.

Cement and Cementing: Innovations in the selection and control of cements and the methods of cementing are continually being introduced as better understanding of this engineering problem is gained. It is well known that commercial cements have almost as many variable characteristics as human beings and, like-wise, they have their individual limitations. To overcome this, the engineer has tested and grouped cements in accordance with the manufacturer's specifications. The petroleum engineer selects the cement best qualified to meet the given problem with respect to thickening rates, strength, slurries, etc. However, there is no common control or exchange of data. The manufacturers can render a big service by furnishing the operators a guarantee that their cements will fall within certain limits with respect to thickening rates, strength, etc.

Cementing methods are also undergoing a change. It has been found that bulk cementing is coming into accepted practice in the oil fields of California. The bulk methods employ large containers, some with screw conveyors, to handle large quantities of cement. Yet this type of equipment and the methods used are still in their infancy and offer tremendous possibilities for savings of time and money in their employment. The maintenance of certain cement slurries is also advisable. It is a problem, however, not generally understood by all operators although it is understood by most engineers. For example, a given cement with a 50 percent slurry will have as much initial strength at the end of the first 24-hour period as will the same cement at the end of a seven-day period if a 60 percent slurry is used. All these factors mean that if the operators resort to a lower slurry, they can drill out and proceed with their work at the end of 24 hours; whereas, if they use higher slurries, it will require a wait of several days in order to obtain the necessary strength of cement.

Mud: Drilling mud, in my opinion, constitutes one of the principle economic factors in the control of drilling speed, hazards of the hole, and other phases of drilling. Operators, in general, give too little heed to their mud problems. I have in mind a splendid example of the employment of mud men or engineers who go through the formality of making tests, and yet the drillers pay little or no attention to the recommendations made; whereas in an adjoining field, another operator has an engineering-trained representative working with each crew, with the result that they have had phenomenal drilling time and little or no hole trouble.

Selection of Casing: The selection of casing size for a given job in ordinary oil field practice produces a rather peculiar situation. A recent study made in California showed all sizes and types of casing and hole sizes to reach the same objective. Variations of casing programs by the same operators were noted from one field to another—in fact, all types of inconsistencies. This brings out the point that too few operators, in selecting the size hole to be drilled and casing size to be set, approach the matter as a program to be pre-analyzed, taking into consideration:

(a) the long term economic outlook of the field;

(b) the subsurface conditions to be overcome;

(c) the effects of hole size on the recovery of oil, if any;

(d) the initial cost;

(e) the ultimate cost.

In addition to the above, consideration should be given to the ultimate advantage, which, of course, will include the maximum returns for the least expenditure of money and the advantage gained in the production of the well throughout its life, in the movement of production tools in and out of the hole, and in the handling of production flow devices and adequate size pumping equipment in and out of the hole. Too few operators give heed to the fact that once the column of steel has been inserted into the well from the surface to the oil zone, they forever set the characteristics and limitations of that well by throttling it with a column of steel.

Deep Hole Production: Many articles on deep hole drilling have appeared in our oil field publications and technical magazines, but very few have outlined the proper design of production equipment for efficient oil recovery once the deep well has stopped flowing. This ties in with the selection of casing and constitutes a very important economic factor in both problems.

Above, H. M. Staggs, Atlantic Refining Company. Left, modern heavy drilling equipment in California.

(C) Cy La Tour

Deeper Drilling Has Encouraged Improved Method

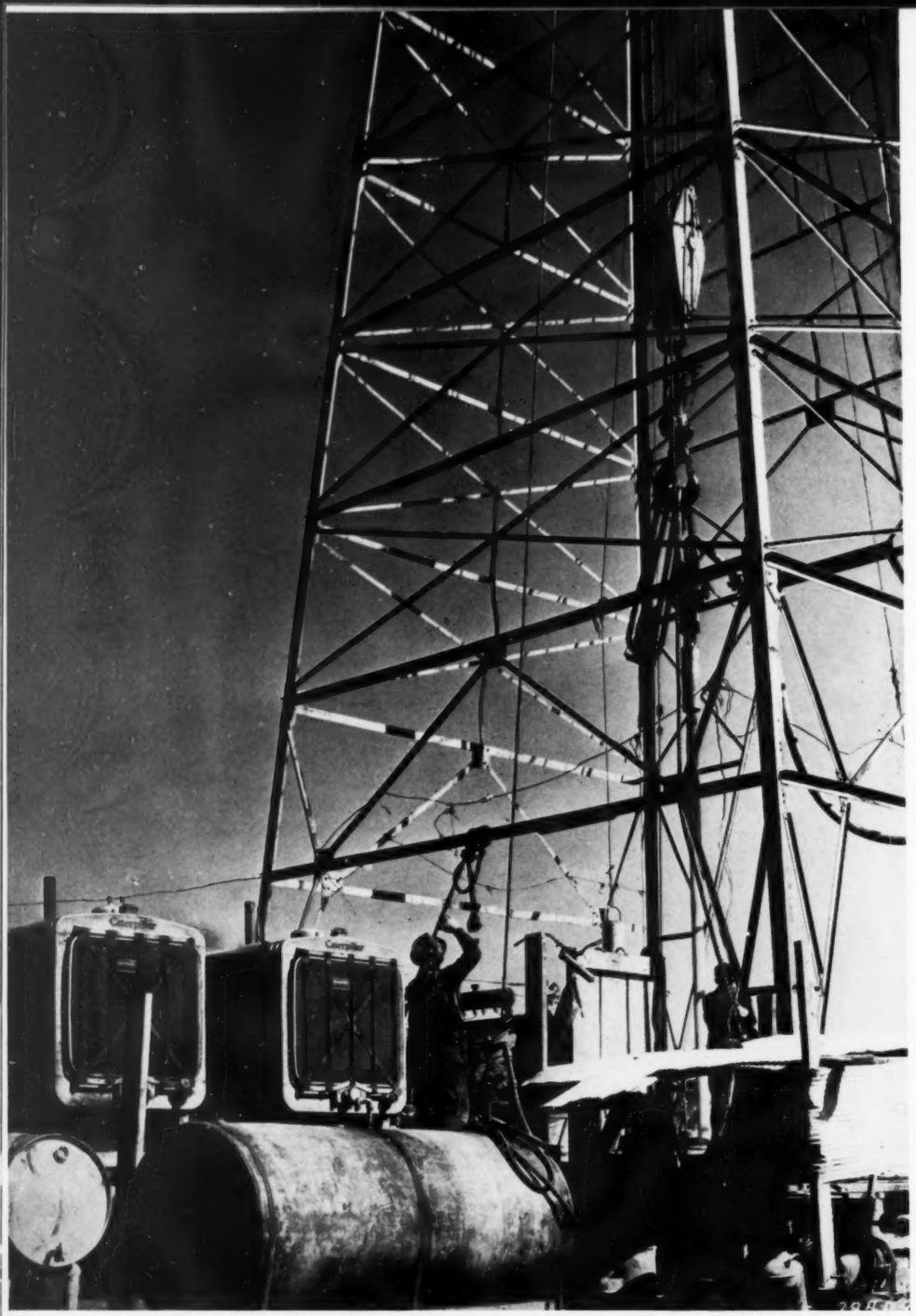
By H. M. Staggs

The Atlantic Refining Company

PRESENT methods and equipment are developing along lines best suited to meet field conditions in oil field drilling. This process of development is one in which the field, the laboratory, and factory are cooperating in determining and solving problems. This cooperation has accomplished much and no radical changes appear necessary or likely.

Many factors have contributed and will continue to contribute to improve drilling practice and improve machinery. During the past twelve or fifteen years, drilling speed has been increased by one hundred percent while fishing jobs have been decreased by more than fifty percent. At the same time, drilling contract prices in deeper drilling have been reduced by thirty percent, and in the shallower areas by fifty percent or more. Holes are drilled much straighter, are better cased, and better cemented. Records of all kinds are kept much more accurately, wells are better completed, and accidents connected with drilling operations have been very materially decreased. Problems coming up as deeper drilling has been required have been met and either partially or wholly solved. This has cleared the path for further progress in improved drilling practice.

The trend today is toward making a drilling operation, either exploratory or development, a completely planned operation. This planning is done by engineers having knowledge of drilling



Two Caterpillar Diesel engines driving mud pumps and drawworks, an example of the trend toward mechanical rigs.

equipment and the difficulties connected therewith, as well as the timely use of specialized services in logging, mud, cementing, and other such services.

In the not distant past, design of drilling equipment was particularly difficult because the designer could not be given much information regarding the stresses equipment would undergo. The trend has been, and will continue, to provide instruments to furnish such information.

Most of the major trends in drilling practice have been brought about by the necessity of drilling deeper holes. To accomplish this, safety and economy must enter the picture, since increasing depths mean increasing risks and cost. Super pressure sands are often encountered in deeper drilling and these incur the danger of losing both the well and drilling machinery and resulting in surface damage and loss of reservoir fluids. Present trends are toward giving more attention to drilling muds, but frequent analysis are made to determine presence of oil and gas and change in salt content. A recent contribution to safety has been the gas detector and oil fluoroscope. With these instruments, it is possible to detect the presence of gas and oil more quickly and surely than is possible without their use. Many blowouts on drilling operations are no doubt caused by drililng a gas sand at too rapid a rate, resulting in reduction of mud weight to a dangerous point. With fluid-operated blowout equipment and cutting not over two or three feet of new sand until the returns reach the surface, much of the risk of losing control of the well is eliminated. The trend has been toward higher drill pipe rotation speeds, thus requiring less weight on the bit and using longer drill collars. In some instances, reamers are used to prevent wobbling and to keep the hole vertical and out to gauge.

In recent years, the trend has been toward portable derricks for rotary drilling where the depths are not in excess of 5000 ft.

The drilling of wells in coastal waters has brought about the use of submersible drilling barges in place of piling. The use of such barges facilitates the movement of the rig from location to location and at much less expense than is otherwise possible.

There is a trend toward the drilling of smaller holes and the use of smaller casing. This results in lower drilling cost and a considerably reduced cost of the completed well. For sometime past the trend has been toward the practice of drilling completely through oil sands and cementing casing on bottom, followed by gun perforation. Undoubtedly, this trend will continue. The practice of drilling out cement plugs with tubing for drill pipe is now widely practiced. This usually eliminates the need for an extra string of small drill pipe.

To aid in assuring successful cementing jobs, casing guides to center the casing in hole and underreaming to enlarge the holes above and below the desired producing formation are practices now being followed. Trends are toward use of electrical surveys, oil and gas detectors to reduce expensive coring, and the practice is rapidly expanding. In cases of exploratory wells, oil and gas detectors are now often used to locate proper coring points or the zones for drill stem testing.

Long liners, three thousand feet or more in length, are being successfully used to reduce casing requirements. These liners are being cemented from the bottom to a short distance above the base of the next larger string of pipe. These liners take the place of string of casing which necessarily continues all the way to the surface. Deeper drilling has brought about the use of progressively heavier drilling machinery and more power, and drilling speeds far in excess of those of a few years ago.

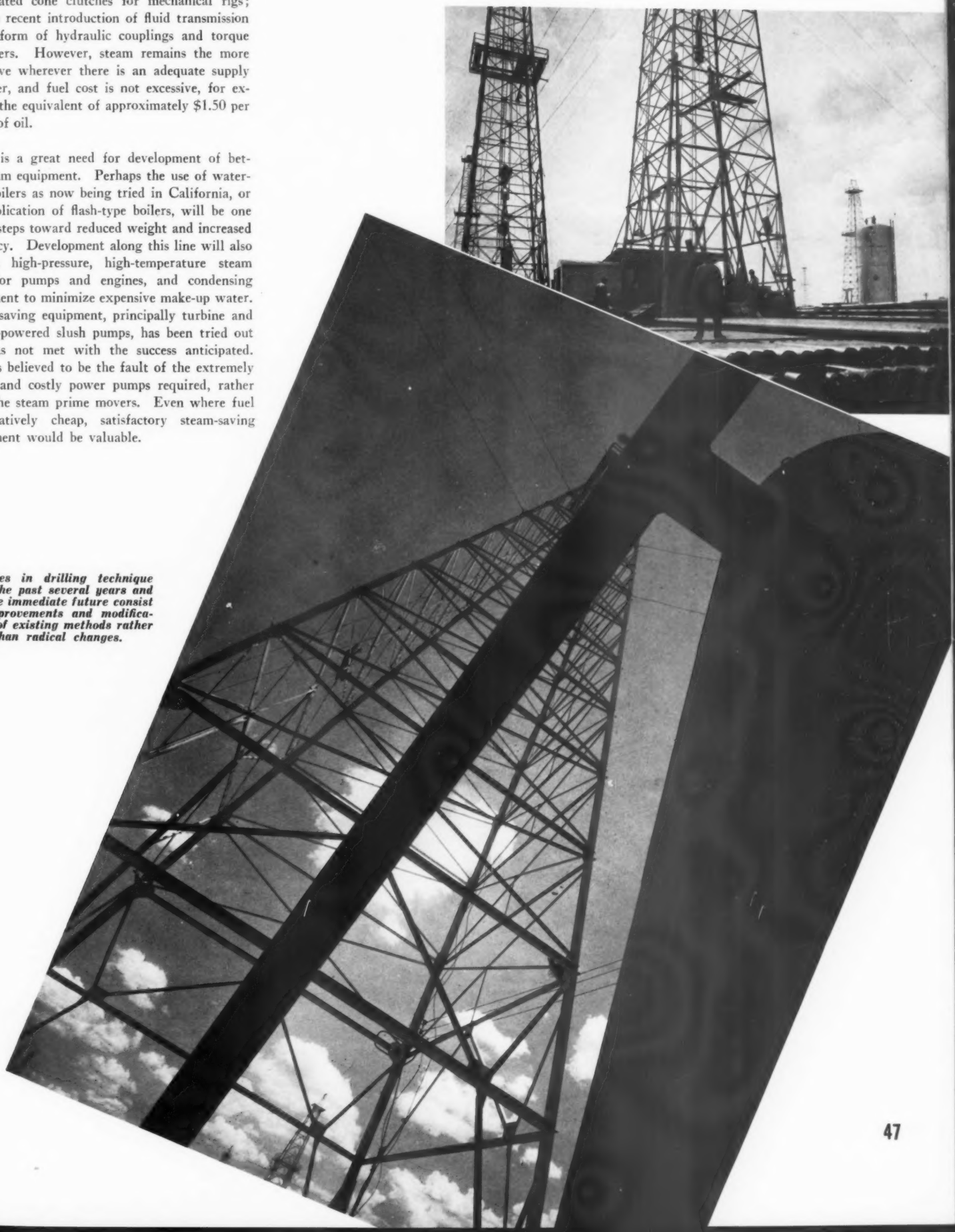
The trend toward keeping engineers constantly on difficult drilling operations is rapidly increasing toward universal practice.

Undoubtedly, improvements in drilling practice will continue to be accomplished and it is my opinion they will come about from careful study and experiments by those experienced in present-day drilling and manufacture of drilling equipment.

Broad Field For Rotary Rig Improvement

MUCH attention in the past has been given to the development of power rigs, such as the introduction of the Ward-Leonard system of control, making possible the modern direct-current powered rig; hydraulically and pneumatically actuated cone clutches for mechanical rigs; and the recent introduction of fluid transmission in the form of hydraulic couplings and torque converters. However, steam remains the more attractive wherever there is an adequate supply of water, and fuel cost is not excessive, for example, the equivalent of approximately $1.50 per barrel of oil.

There is a great need for development of better steam equipment. Perhaps the use of water-tube boilers as now being tried in California, or the application of flash-type boilers, will be one of the steps toward reduced weight and increased efficiency. Development along this line will also require high-pressure, high-temperature steam ends for pumps and engines, and condensing equipment to minimize expensive make-up water. Steam-saving equipment, principally turbine and engine-powered slush pumps, has been tried out but has not met with the success anticipated. This is believed to be the fault of the extremely heavy and costly power pumps required, rather than the steam prime movers. Even where fuel is relatively cheap, satisfactory steam-saving equipment would be valuable.



Changes in drilling technique over the past several years and for the immediate future consist of improvements and modifications of existing methods rather than radical changes.

Four 60 kw Diesel-electric units mounted on a twenty-ton trailer. The control panel can be seen at the rear.

The most needed item of drilling equipment for both power and steam rigs is a rotating type of pump, such as a rotary or centrifugal pump, to get away from the heavy, expensive power slush pump and the inefficiency of the reciprocating-steam slush pump. To date, experimental equipment of this nature has failed, due to the combination of abrasive drilling fluid and high circulating pressures.

Another possibility is the development of a suitable device for properly spooling drilling line on the drawworks drum at higher speeds so that a larger number of lines could be strung, allowing lighter-duty drawworks.

There are cements available today that will remain pumpable for six hours and yet have sufficient early-setting strength to permit drilling ahead in twenty-four hours or less. Such cements should result in lowering of time while waiting on cement to set, from the present forty-eight to seventy-two hours, to not more than twenty-four hours. To take advantage of this faster-setting cement time it will be necessary to improve our rigs to the point where the periods after setting casing now used to complete rigging up and for maintenance of equipment, will not exceed the actual time waiting on cement to set. One of the striking peculiarities of drilling operations to a power plant engineer is the general tendency to let "well enough alone" as long as equipment seems to be working satisfactorily, rather than having definite periods for inspection and replacement of parts. Public utilities long ago found that a definite maintenance program improves efficiency and operating economy. If the majority of repairs and changes could be made during cementing time, an extra crew, and perhaps the equivalent of a master mechanic, may be justified. It must be remembered that of the approximately $15 to $20 hourly cost of a drilling rig, only one-third is represented by crew labor.

Transportation of a drilling rig costs from $10,000 to $20,000 per year of continuous service. The better use of alloy steels, or the substitution of light-weight materials such as aluminum and magnesium, not only will reduce transportation costs, but may lead to stronger design with less downtime for repairs and replacements, and to more extended use of unitized designs, with consequent reduced rigging up and tearing down time. Such developments naturally must wait until the current world war is over, but the present expansion of the steel and other metal industries should certainly make the material more accessible after the war.

The stress in a 16,000-ft. string of Grade D drill pipe is close to the elastic limit. It is therefore probable that greater use will be made of steel with physical properties superior to Grade D when drilling below 10,000 ft.

The elimination of the weak threaded connection between drill pipe and tool joint by use of integral construction or flash welding led to the development of double-pin subs, and more recently, double-box subs, the latter having the advantage of a cheaper replacement cost. These subs permit the economical use of oversize diameters to protect the pipe ends of the tool joints from wear. Pin and box threads of tool joints on drill pipe now give very little trouble, and doubling the number of such connections by using double-pin or box-and-box subs presents no disadvantage.

Hardened tool-joint surfaces have been found highly desirable to reduce wear. Before they can become entirely satisfactory, a tong capable of gripping the hardened surfaces must be developed.

Drill collars continue to be a major source of drill string failures, due to improper joint design, conventional tool-joint design offering insufficient support to the long column. Several designs incorporating a longer pin are now being tried.

In wells completed below a depth of 7000 ft. in the Gulf Coast area there is a marked decrease in footage drilled per hour as well depth increases. This may be attributed to one or more of the following causes, (1) reduction in rate of circulation of drilling fluid; (2) increased hardness of formations; (3) tendency to be more cautious with respect to speed of rotation and weight on bit due to increased hazard of drill string failures and to avoid crooked holes. The first loss may be overcome by increased slush-pump capacity or higher steam pressures; the second by increased weight on bit and speed of rotation; and the third by improved drill pipe and drill collars. The benefits to be derived from these improvements doubtless will be reflected also in the more shallow fields.

Weight indicators, torque instruments and tachometers should be made more accurate and more durable for maximum utility. Simple but accurate direct-reading pump speed and rate-of-penetration instruments are in process of development. With the knowledge obtained with these instruments concerning the factors affecting rate of penetration, it is logical to believe that automatic drilling controls will be feasible. With regard to improvement in drilling fluid, there is still considerable room for progress by reducing the thickness of the mud sheath left in the hole, in order to increase the ability of the well to produce and to facilitate drilling. It has been reported that there has been some work done in Russia in using chemicals in the drilling mud to make some formations more drillable.

There is also a distinct possibility that more extended use of mud-logging devices will result from the technique now being developed and from increased knowledge in interpreting the result of the analyses. There have been several wells drilled in which no regular wire-line cores have been taken, entire reliance being placed on mud logging, electrical logging, and side-wall sampling.

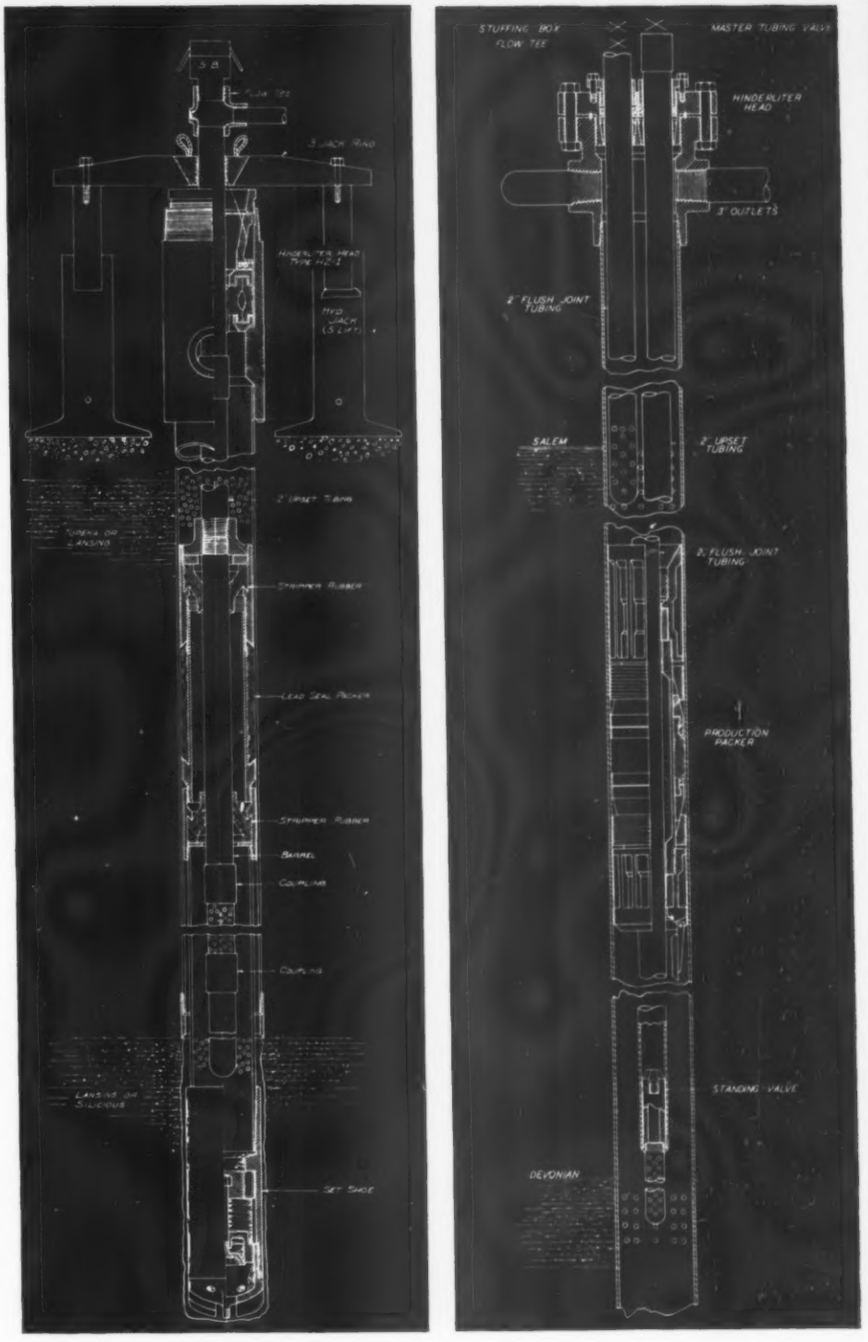
In completion practice, savings are effected by the method wherein the casing is set at the top of the sand and no screen or liner is used to protect the open hole. In the Gulf Coast area, open holes in producing sands which appear to stand up as long as clean oil is produced, fail when the well starts making water. More knowledge of the factors affecting the ability of sand to stand up must be obtained before open-hole completions can be confidently utilized.

Setting casing about 10 ft. above the oil-water contact, then progressively plugging back as the water level rises, has been found highly desirable where producing horizons are thick enough to permit this practice. The success of this procedure depends primarily on the effectiveness of the cementing job on the oil string of casing.

E. A. Jenkins, Efficiency Superintendent, Skelly Oil Co., Tulsa, Oklahoma.

Economies in Selecting Casing

By E. A. Jenkins
Efficiency Superintendent
Skelly Oil Company



Left, a single tubing string well producing from two pay zones. Right, well producing from two zones through two strings of tubing.

DURING the past several years conditions in the oil industry have forced closer scrutiny of every item of expenditure in connection with the drilling and producing of oil wells.

Not so long ago 7-in. casing, whether run in a 2,000-ft. well or one 5,000 ft. deep, usually weighed 24 lbs. per ft., while 5½-in. casing weighed 17 lbs. per ft., regardless of the depth of the well. This, of course, was partially due to a limited number of grades and weights from which to choose. Now, however, with a greater number of weights and grades, closer selection as to the exact need is possible. The practice is now more general to balance grade against weight, and to select the pipe which will meet all conditions imposed by a well of a given depth and result in the lowest delivered price to the location. For instance, we have a well 4,500 ft. deep which we wish to complete with 7-in. O. D. casing, and we find that 7-in. 20 lbs. J-55, 20 lbs. N-80, and 22 lbs. H-40, all have physical properties which closely approach those demanded by a well of this depth, but after checking freight rates and mill prices on the various weights and grades of pipe, we find that 7-in. 20 lbs. J-55 most closely fits the need and will give us the lowest delivered price. This plan carried to its logical end in deep wells causes us to select several different grades and weights of pipe to be run together, each with characteristics to fit the conditions found in the portion of the hole in which it will be located. For instance, if we assume a 10,000 ft. well is to be cased with 5½-in. O. D. casing, using, for example, a four-way mixed string of pipe, the lower 2,000 ft. of pipe being 5½-in. O. D. 17 lbs. N-80, the next 2,500 ft. above being 5½-in. O. D. 17 lbs. J-55, above which 3,500 ft. of 5½-in. O. D. 15 lbs. J-55 is to be run, the top 2,000 ft. of pipe could be either 5½-in. O. D. 17 lbs. N-80 or 17 lbs. J-55 with long couplings. In practice, usually a three-way mixed string will prove nearly as economical, and there is less danger of confusion in handling the different grades and weights.

There, too, has been a swing, for reasons of economy, to smaller diameter casings in wells. A few years ago, 7-in. O. D. casing was used as the inside or oil string in the majority of wells, with 5½-in. O. D. and 8⅝-in. O. D. being used to some extent. We now find very few wells completed with 8⅝-in., and the trend is towards 5½-in. O. D., and even smaller casing. The use of small diameter pipe, 5½-in. O. D., 5-in. O. D., and 4½-in. O. D., run in small drill holes, usually 6¾ in. to 7¾ in. in diameter, is classed in the industry as slim hole drilling, and has been discussed at length in several well written papers. However, the small diameter casings can be run in the standard size of hole with success and economy.

Producing conditions and problems must also be considered in choosing casing sizes. As a further economy, two zone completions are becoming more common; that is, two separate producing horizons are tapped and produced through a common drill hole and string of casing. This is accomplished by setting the casing on or through the lowest producing formation, and then perforating or milling out the section of casing adjacent to an upper productive zone. Then by setting a packer between the zones they may be produced; one through a tubing string, and the other through the annular space, or through two strings of tubing in the same well.

TRENDS in Deep Drilling Equipment & Practice

By Arthur G. Levy
Chief Engineer, Fohs Oil Company

DEEP drilling is a complex problem involving adequate powers, effective machinery, suitable tools, high grade tubular goods (drill pipe, casing and well tubing), accurate scientific instruments and devices, an intelligent application of physics and chemistry to the composition and control of drilling muds, and finally an engineering and operative personnel of high competence.

Steam remains the most flexible and reliable power available. Wherever fuel gas is free or cheap and water is plentiful, it is also probably the most economical. Wherever steam is used, the steam generating units should be carefully engineered for efficiency and economy. It goes without saying that burners and fireboxes should be chosen and designed for optimum combustion; that all boilers and lines should be insulated against heat losses; that exhaust steam should be utilized to pre-heat boiler water; that boiler water should be treated chemically to eliminate scale-forming particles. The present trend is toward higher pressures, and probably toward super-heated steam.

Internal-combustion power (gas, gasoline, butane or Diesel) whether converted to electric power or not, is definitely indicated where free or very cheap gas is not available or where water is scarce. Modern internal-combustion powered rigs, particularly Diesel-electric and Diesel-mechanical, are capable of drilling to depths of from 12,000 to 15,000 ft. as rapidly and as satisfactorily as steam-powered units of comparable horsepower. Diesel-electric powered units are in most important respects as flexible as steam powered units. Diesel-mechanical powered units are somewhat less flexible in operation than steam and do lack a little bit in hoisting speeds at great depths, owing to the tendency to stall at high torque at low speeds. This deficiency can probably be eliminated by the development of a satisfactory hydraulic transmission or a torque converter. Regardless of their minor shortcomings internal-combustion powered rigs are steadily coming into more general use, because of the appreciable savings effected in fuel and water consumption. An average well of depth of 10,500 ft., requiring 60 days to drill, will consume from 10,000 to 15,000 bbl. of fuel oil, costing on location from $12,500.00 to $18,750.00—if drilled with steam. The fuel for an internal-combustion powered rig to a similar depth would cost from a minimum of $2,500.00 for Diesel fuel to a maximum of $4,500.00 for butane. This represents a saving that the industry can ill afford to overlook, either from the viewpoint of economy or conservation.

As between steam and internal-combustion power—the trend is toward the latter.

When the drilling of deep wells, that is, wells below 9,000 ft., was first attempted, most available equipment was inadequate or barely adequate. Certainly it was uneconomical. At once there arose the demand for heavier units, larger swivels, rotaries, blocks, pumps, and more powerful engines. Then in rapid succession came wells of depths ranging from 11,000 to 15,000 ft. Rigs became larger and heavier. The more recent trend has been in the direction of improved engineering design, utilizing higher grade alloy steels, higher capacity bearings, finer machining, better controlled heat treatment and more effective carborizing, together with a myriad of other refinements—all calculated to provide speed and capacity and at the same time reduce weights and increase portability.

The trend in draw-works is toward oil-bath units, completely enclosed—the sprockets forged and precision cut and the chains of the high speed precision type. Both chains and sprockets of double or multiple width are becoming more common. Shafts are of high grade alloy steels and heat treated. Bearings are designed for high speeds and heavy loads requiring special hardening and fine machining.

The trend in swivels and rotaries, as well as crown blocks and travelling blocks, is toward higher capacities at increasingly high speeds. In this connection the problem is largely one of bearing design and metallurgy. The bearing manufacturers have kept well abreast of the problem. These items of equipment are of prime importance, because there appears to exist a direct relationship between speeds (rotational and hoisting) and rate of penetration.

The trend in mud pumps is toward greater volumes at higher pressures. These are achieved by longer strokes and more power. Mud circulating pressures are becoming higher, commensurate with depth of drilling and the necessity of increased mud weights. In steam (duplex-reciprocating) pumps this condition requires larger diameter steam cylinders and higher pressure steam. In mechanical power-driven pumps this condition requires higher capacity of prime-movers and reduction gears capable of transmitting this power to the fluid pistons. Generally speaking, higher sustained circulating fluid pressures are possible with power-driven pumps than with steam-driven pumps. Capacities of 18 bbl. per minute at 1,000 psi or of 9 bbl. per minute at 2,000 psi, requiring from 450 to 500 hp. are now essential. Correspondingly higher pressures may be obtained by operating two or more pumps in series, referred to as "compounding." The writer has on one occasion observed a mud circulating pressure of 3200 psi in drilling. Circulating pressures of the order of 2500 psi are common. An important advance could be made by the design of an horizontal-triplex pump capable of from 14 to 15 bbl. per minute at a sustained pressure of 2,500 psi. Such a pump requiring from 900 to 1,000 hp. will very likely be the next development.

The trend in steam engine design is toward more power and higher speeds. Vertical engines (duplex and triplex) find some favor. Even multi-cylinder steam engines are being used more or less experimentally. These engines do apparently have certain advantages, particularly in the relation of steam consumption to horsepower. The conventional horizontal duplex steam engine remains most generally used. However, the most logical development to be expected in steam engines would be an horizontal-triplex engine of the order of 1800 to 2000 hp. at a steam pressure of 300 psi.

The trend in internal-combustion engines is definitely toward heavy duty Diesels. Other engines represent a lesser initial investment and operate at higher speeds; are consequently somewhat more flexible. Low speed heavy duty Diesels of large bore and medium stroke, are longer lived, require less attention, and are generally more reliable.

The trend in drill-pipe is toward streamlining, inside and outside, together with the use of higher yield steels. Welded-on, shrunk-on, inte-

Above, large capacity pumping well in mid-continent; left Arthur G. Levy, chief engineer, Fohs Oil Co.

gral and flush joints are all competing for favor. The trend in well casing is in the direction of smaller diameters and the use of higher grades of steels—the former in the interest of economy and the latter in the interest of strength (tensile and resistance to collapse) as well as reduction of tonnage. Special casing joints are meeting with considerable favor in the interest of elimination of thread leaks and higher efficiencies in tension. The conventional thread and coupled joint with long collars, 8 threads (round) per inch, are most commonly used and appear to be generally satisfactory.

Pipe weight indicators are on all rigs. Automatic recording devices such as tachometers horsepower indicators, and rate-of-penetration recorders are in use on some rigs. Devices for recording the physical and chemical characteristics of drilling muds are also in use. There are devices for detection and measurement of entrained gas in drilling muds, as well as a device for the fluoroscopic examination of drill cuttings and cores. Core-analysis services are being used to a considerable extent for the purpose of selecting perforation points in completions. Services are available for conventional electrical logging, continuous electrical logging, and surveying.

There has been a tendency to try to find a suitable substitute for barytes as a weighting material for drilling muds. Among other minerals suggested and tried are finely milled silica, limestone and celestite (strontium-sulphate). Of these materials probably celestite is most nearly suitable. It has, however, not been very widely used, owing to the presence of certain impurities which complicate the chemical treating problem, and make necessary the use of larger quantities of phosphates. Iron-oxide has been widely used in the past, but is used less generally today than it was a few years ago. Barytes for weighting together with bentonite as a colloidal agent remain the most generally used materials.

Starches are being used experimentally and practically in certain localities as an additive to clay base muds, partly as a substitute for bentonite in reduction of free water, but more particularly in connection with muds of high saline content. In high salt concentrations certain starches have been used successfully in preventing flocculation, water losses and incompetent filter-cakes. In fresh water muds uncooked starches tend to ferment, but this deficiency has been corrected by small additions of para-formaldehyde. Certain gums have also been used recently, both together with and independently of starch. These gums are becoming difficult to obtain and will probably not be available for general use.

The trend in chemical treatment is more and more in the direction of the polyphosphates with sodium-tetra-phosphate probably the most generally used. Sodium-tannate and sodium-gallate are still in use in varying proportions, but are probably not as generally used as they were a few years ago. Where starches are used in the mud in proportions as high as from two to four pounds per barrel of fluid, phosphates would probably enhance fermentation. Consequently sodium-tannate or sodium-gallate might be indicated as a treatment in lieu of phosphates prior to and after addition of starch.

The trend in cement is toward a retarded setting under conditions of high temperatures and pressures. It is quite apparent that the characteristic of impermeability is more important than structural value in oil well cements, and as a consequence bentonite-cement is being considered with increased favor.

Preventative squeeze jobs are becoming more and more common prior to gun-perforating for production wherever water is present close to the objective horizon and wherever there is reason to believe that the original cementing may be faulty or inadequate.

Stage cementing has been advocated and used more or less for some time. At the present time new devices for its accomplishment are being offered and may conceivably extend its use. The main objection has been trigger work and lack of simplicity.

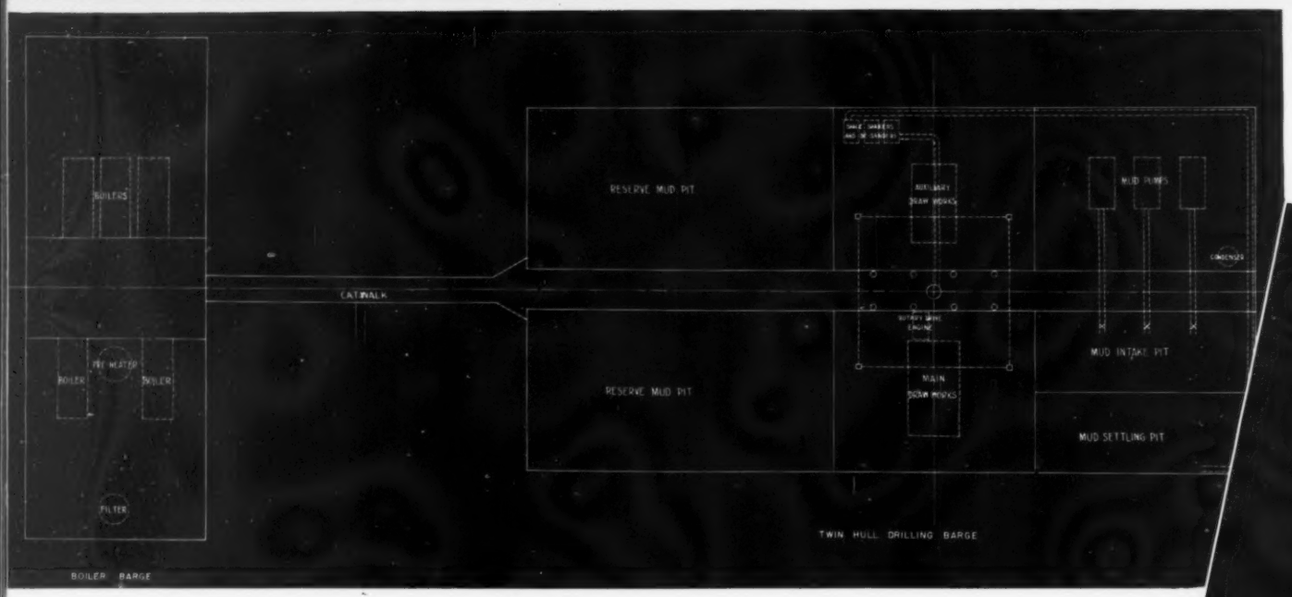
Wall cleaners are being used more extensively of late, particularly spring wire contraptions fixed to the outer wall of the casing for the purpose of removing competent filter-cakes and centering prior to the placing of cement. Many operators believe that this procedure may materially improve original cementing and perhaps eliminate a certain number of squeeze jobs. The trend in cementing is toward the use of larger volumes of cement based upon doubt as to actual hole diameters. In this connection accurate inside calipers are a special need as a basis of determining cement volumes. An indication of oversized holes is apparent in the magnitude of a hole carry-over in the mud systems on many deep wells.

The most important problem facing the oil industry at the present time is the knotty one of keeping down capital investment and intangible drilling costs. The former may be reduced by the use of smaller diameter casing, combination strings, smaller tubing sizes, and the elimination of well screens, liners and packers, wherever these may be dispensed with safely. The latter may be decreased by faster drilling, careful and economical control of drilling muds, and the elimination of unnecessary coring.

In connection with rate of penetration it is probably true that high rotational speeds have been proved effective. In many instances reductions in diameters of well bores, made possible by smaller casing diameters, have increased drilling speeds nearly in proportion to cubic feet of excavation—that is approximately in the relationship of the squares of the diameters of the holes drilled. Where this is true an added saving is effected in the cost of the smaller bits used. This relationship is by no means universally true. In the softer tertiary beds of the Texas and Louisiana Gulf Coast there appears to be only a very slight, if any, difference in the rate of penetration between a 9.875 in. hole and an 8.5 in. hole, though the relationship is of the order of 1.35:1. There appears to be a definite trend toward reduction and even elimination of coring in proven areas. After gas/oil and oil/water contacts have been determined, and the physical characteristics of the reservoir have become known, satisfactory completions can be made upon the basis of electrical logging. In semi-proved and even in wildcat areas there is some tendency to avoid conventional coring in favor of sidewall cores based upon revelations of electric logs.

In all drilling, the time consumed in withdrawing pipe from the hole and running the pipe back into the hole for the purpose of changing bits, coring, reaming, surveying and testing is considerable. For this reason, ample power to speed up these operations is vital; likewise machinery of modern design in first class condition and well trained crews, as well as highly competent supervisors, are indispensable.

These trends are all dependent upon the availability of high grade material and highly trained personnel. The immediate future presents certain obstacles to their continuation. The curve of progress may very well be leveled out by forces beyond control. High grade alloy steels, steel plates, Diesel engines and repair parts are already difficult to obtain; may soon become unobtainable. Fine machining, heat-treating and hard-surfacing require machinists and metallurgists with specialized training. The direct rearmament effort may drain so-called civilian industries of these services.



Schematic lay-out of drilling barges on location.

H. M. Livezey, chief petroleum engineer, Plymouth Oil Co.

12,000 Foot Well in 58 Days Exemplifies Drilling Progress

By H. M. Livezey

Chief Petroleum Engineer, Plymouth Oil Company

THE completion of a producing well at a depth of 11,619 ft., by the Humble Oil & Refining Company, in Southern Louisiana in 1938, was a remarkable achievement. The work had required an elapsed time of eight months. Although the heaviest available equipment was used, and the best engineering principles employed, the drill pipe was stuck at 8,750 ft. and after several attempts to recover, the hole was sidetracked.

After the completion of the well, other wells were drilled to this and greater depths. Equipment and engineering practices have improved until it is now possible to drill a 11,000 or 12,000 ft. well with no more difficulty than 5,000 and 6,000 ft. wells were drilled a few years ago. An example of this was the recent drilling of the Plymouth Oil Company Jeanerette No. 1, in Southern Louisiana, to a depth of 11,934 ft. in 58 days elapsed time. The elapsed time included setting and cementing 199 ft. of 16-in. conductor pipe and 1,966 ft. of 10¾-in. surface pipe, taking six electrical logging surveys, taking 68 wire line cores and 65 side wall cores, one fishing job, and one drill stem test at 8135-59 ft.

The drill pipe was twisted off 150 ft. above the drill collar when the well was at 11,087 ft. The mud and hole were in such good condition that the fish was not stuck.

The progress made in equipment and engineering practices can be further appreciated when it is considered that this well was located in marshy land and could only be reached by an 18-mile boat trip.

The well was drilled with one of the largest drilling barges built. Canals were dredged from the Bayou to the location to permit floating the barges in.

The equipment consists of a 136 ft. rig with a 30 ft. base mounted on two barges each 135 ft. long, 32 ft. wide and 10 ft. deep. The barges were floated to the location, and spaced eight feet apart along eight piles which had been driven. They were fastened together with special X frames, and allowed to sink by opening the sea cocks. The space between the barges was then filled in, both at the barge level and the derrick floor level, to form one large barge, 145 ft. by 72 ft. The derrick was mounted in the center of the barges. Built on the barges are two reserve mud pits with a capacity of 2500 bbl. each. On top of these pits are skids, for storing drill pipe when moving and placing the casing when drilling the well. On the other end are located the mud settling and mud intake pits, mud pumps and steam condenser. Underneath the derrick is a rotary drive engine and shale shakers and desanders. On the derrick floor level are living quarters for the crew and a dry mud storage room is built on the end opposite the pipe racks.

One drilling barge and boiler barge.

The main draw-works are driven by a 14 in. by 14 in. engine and the standby draw works, on which the core line is mounted, is driven by a 12 in. by 12 in. engine. The rotary table is driven by a 12 in. by 12 in. engine.

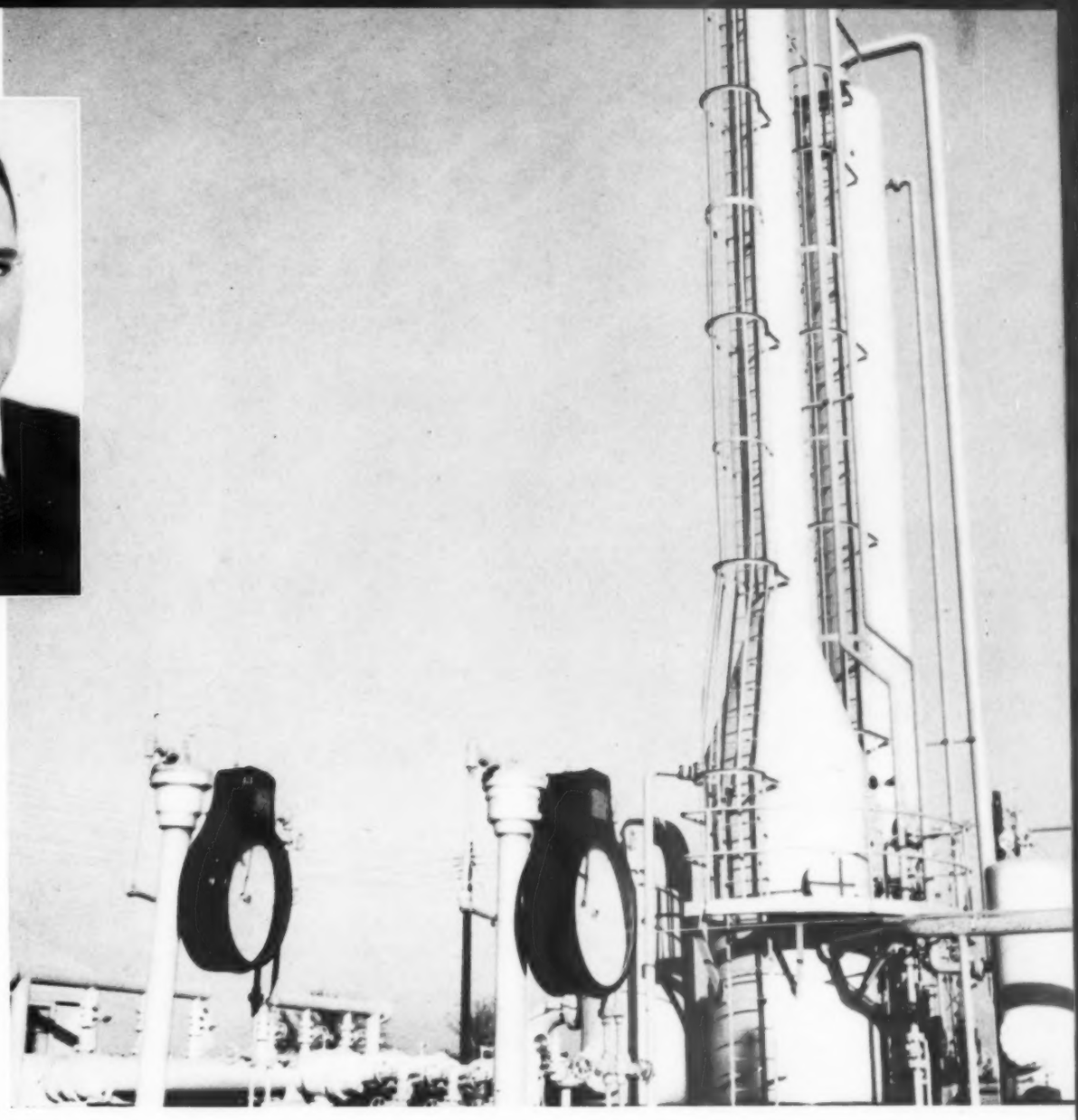
The three 8½ in. by 20 in. mud pumps are arranged so they can be compounded and deliver a maximum pressure of 4,000 lbs. In normal operation one pump is used for circulating through the drill pipe, one for continuous agitation of the mud in the intake mud pit and the third for a standby.

Steam is supplied at 300 lbs. pressure from five 125-hp. boilers. The boilers are mounted on a separate barge, 100 ft. long, 36 ft. wide and 10 ft. deep. The barge is located a safe distance from the drilling barge and sunk. A steel catwalk connects the boiler barge to the drilling barge and carries the steam lines.

Additional equipment carried on the barge is a complete set of overshots for all sizes of drill pipe and subs to make any connection, a pressure operated blowout preventer, Diesel-powered auxiliary light plant, acetylene and electric welding equipment, sand blaster, paint shop and a supply of dry mud to meet nearly any emergency.

Three six-man crews, each working eight hours, are used. In addition, a tool pusher and mud engineer are on the barge all the time and from three to five extra men on daylight tour to make general repairs and maintenance of the barge.

To insure the safety and successful completion of the well, vertical deviation survey is made each trip out of the hole, but at intervals of not more than 500 ft. The blow-out preventer is tested on each trip. Mud samples are taken and analyzed every thirty minutes after the well is a few thousand feet deep.



Above, Jack H. Abernathy, chief engineer, Sunray Oil Co.; Right, fractionating columns of a modern pressure maintenance plant in Illinois.

The Trend to Pressure Maintenance

By Jack H. Abernathy
Chief Engineer, Sunray Oil Company

WITH a reserve supply variously estimated at about 20,000,000,000 bbl., the oil industry in the United States at the first of 1941 had a larger quantity of oil in sight waiting to be produced than at any time in history. Production in 1940 was about 1,340,000,000 bbl.; thus the reserves represent about 15 years supply at the present rate. Discovery rates are still favorable and vast potentially productive areas are as yet unexplored. Nevertheless, despite new reserve peaks each year the time inevitably will come when reserve discoveries fail to keep pace with production. The industry has the responsibility to seek new reserves. It is equally the responsibility of the industry to discover and exploit means of more efficient extraction of oil from pools already discovered. In the past few years much thought and attention has been given to possible methods of improving recovery efficiency. Current trade journals print many articles dealing with the theory and practice of flooding, repressuring and pressure maintenance. Many old, nearly depleted properties are being reworked successfully.

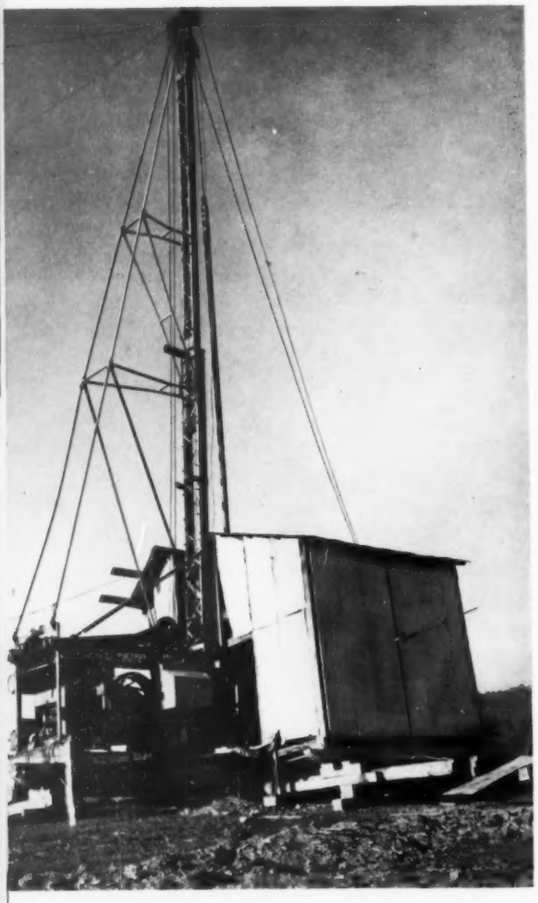
Although producers are beginning to consider the gas compressor as a conventional equipment item, with a few notable exceptions the general practice is to defer the installation of high-pressure equipment, and await the day when repressuring may be utilized, since pressures are decreased by long production, and equipment can be installed at a much lower cost. Many hold the impression that under present low allowables and long payouts, it is better to reduce capital investment to a minimum even at the sacrifice of some efficiency far in the future. The point made here is that the delay may result in cheaper installation, at great sacrifice to ultimate recovery.

These impressions are current because little information has been available dealing directly with the relative efficiencies of repressuring and pressure maintenance. It can be demonstrated that in many gas-control reservoirs where repressuring will add from 20 to 50 percent to primary recovery, pressure maintenance will add 75 percent or more. This means that for an investment of probaly not exceeding 10 percent of well cost, a direct addition to producible reserves of

(Continued on page 108)

Progress Expected in Oil Well Drilling

Above, making a connection on a heavy rig in California; Below, a Bucyrus-Erie portable cable-tool rig making 6¼ in. hole. This light rig was removed in five hours or less at a cost of about $30.



NOTABLE progress has been made during recent years in reducing costs, increasing drilling depths, decreasing completion time in the drilling of oil wells. This progress has been due largely to improvements in metallurgy, design, and field transportation of conventional drilling equipment, in coring equipment and practices, in drilling mud conditioning, and in well completion practices. Although a great deal has been accomplished, there is need for still further reduction in drilling costs and improvement in drilling procedure.

There are many reasons why this need exists, some of the most pertinent of which may be of sufficient interest to warrant reviewing briefly.

Substantial reductions in drilling costs per well would, of course, lower the investment required to develop a field on a given well spacing pattern, and assist in reducing the total investment burden on producing companies in oil field development and operation. This is true in both domestic and foreign development, but particularly desirable in our domestic fields where low producing rates brought about by proration make it necessary that drilling costs be held to a minimum.

A wider use of drilling as an oil prospecting method could be effected if drilling costs could be substantially reduced. Improvement in geological, geophysical, and geochemical prospecting methods can be expected to assist in locating additional new oil fields, but drilling could be more effectively used in conjunction with these methods and in the actual location of certain types of oil reservoirs such as stratigraphic traps if drilling costs could be reduced enough to make the operation economically feasible.

Additional substantial improvement in deep drilling procedure and costs would increase the use of oil well drilling by making it practicable to locate and produce oil from deeply covered reservoirs.

Future progress in oil well drilling may be expected from two major sources. First, continued improvement in conventional equipment and practices may be depended upon as a substantial source of future progress. Second, the development of new methods of drilling.

Displacement, at least in part, of positive drive gears, especially on internal combustion engine driven drilling rigs by hydraulic drives is a problem now being studied and on which progress is being made. When satisfactory hydraulic drives have been developed, shock loads will be reduced to a minimum, longer service can be expected from the drilling equipment, as well as smoother and more efficient use.

More portability of the complete rig without sacrificing service life and drilling speeds after the rig is on location is desirable. Some improvement can be expected in this direction from development of stronger and lighter materials used in the manufacture of drilling equipment. Relocation of the essential parts of the rig, as well as improved design of these units, may be expected to assist in the solution of this problem. The same general remarks are applicable to the casing and most of the other materials used in drilling and equipping the completed well.

Continued improvements in the steel used in casing and tubing are anticipated.: Right, lowering a Lane-Wells 4¼ in. gun perforator into the packing gland.

Lighter Rigs, Better Design for Deeper Drilling

By J. U. Teague
Hogg Oil Company

THE remarkable progress in increased drilling efficiency of the past ten years has been due as much to improvements in drilling technique as to the improvements made in drilling equipment. I think this is well illustrated by the development of a field in the Gulf Coast with which I happen to be familiar. About 1928 this particular field was developed in a sand averaging around 3,500 ft. in depth. At this time it required about thirty days to drill and complete a well to this depth. About 1936 a deeper sand around 4,500 ft. in depth was discovered in this field, and, using the same size rigs and in many instances the same crews as were used in the initial development, these deeper wells were drilled and completed in less than half the time required by the wells in the original development and at about one-half the cost. The difference in this case was improved drilling technique as there was no radical change made in equipment or men.

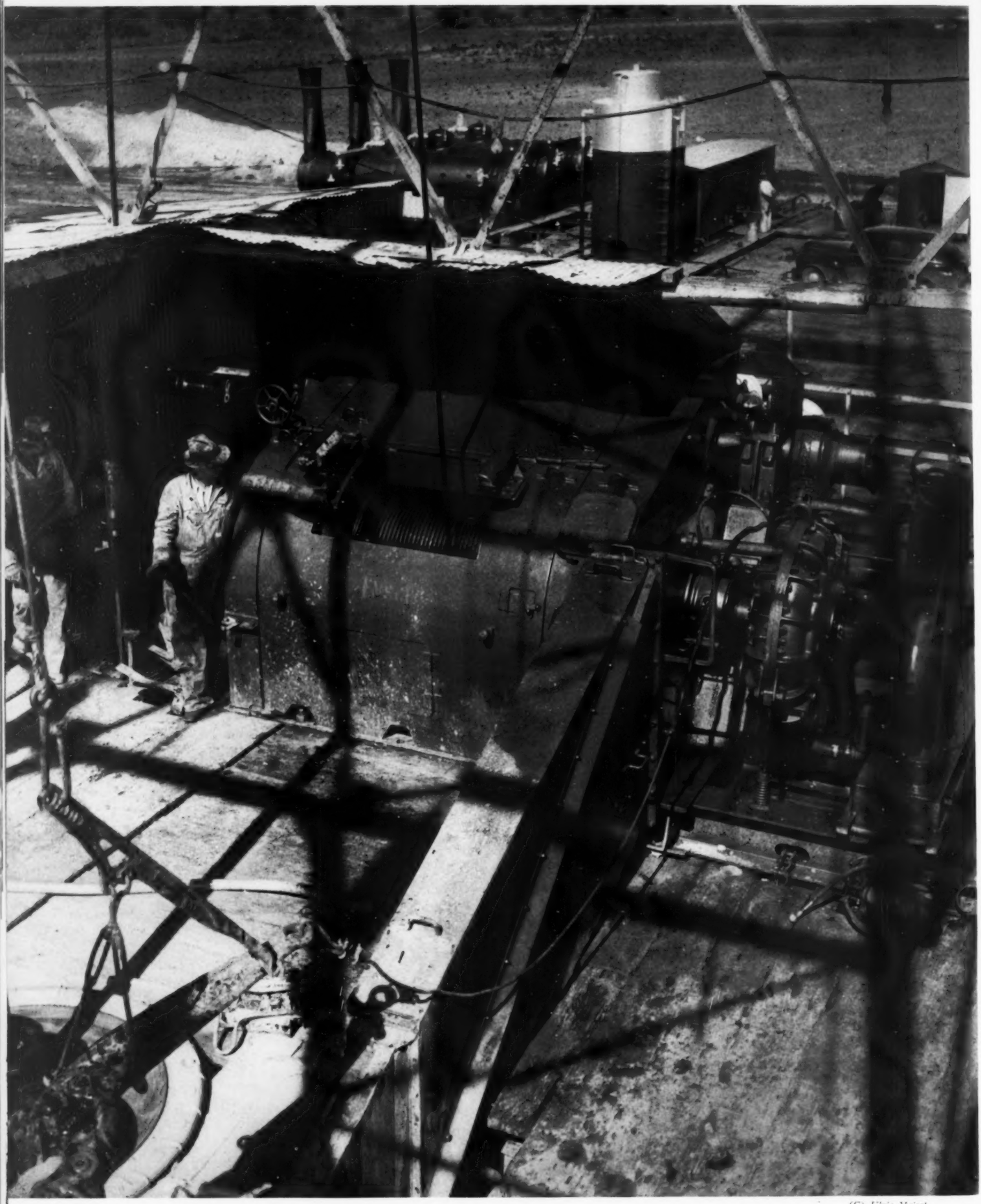
The improvement in drilling technique might be summarized as, 1st., better drilling mud control; 2nd., better bits; 3rd., unitization of drilling equipment; and 4th., better planning and co-ordination of work. In my opinion the continued improvement in the technique of drilling will continue to play a dominating role in promoting more efficient drilling operations.

However, to give all the credit for the increased drilling efficiency of today to improved technique would be entirely erroneous as improvements in equipment have played and continue to play a large part.

In my opinion the most encouraging and significant development in drilling equipment has been the recent development of the medium power driven rigs which are proving so effective in drilling to moderate depths. These rigs are not only comparing favorably, in drilling time, with steam rigs of a comparable rating but they are incorporating basic changes in design which I am sure will eventually find their way into the heavier rigs. I mean by this the use of friction clutches instead of block clutches, gear boxes and V belt drives instead of sprockets and chains, and in mechanically operated drum brakes and clutches instead of manually operated ones. The rigs are light, portable, and far less expensive both in initial cost and cost of operation than the medium steam rig. The power rig is especially desirable in areas where water and fuel are a problem.

The tendency in the past and still expressed in the larger heavy duty rigs for deep drilling has been to hold to the same basic design of drilling equipment and to meet the increased demand for power by continually greater drilling depths by merely increasing the size and weight of the equipment. The result is seen in the huge heavy duty rigs of today which are a joy to the field man in performance but represent a tremendous investment and upkeep cost. It is not uncommon for a 15,000 ft. rig, complete, to cost between $200,000 and $300,000 today. Apart from the large investment the size of the equipment adds to the moving and handling cost. In my opinion we shall see in the near future the adoption into the heavy duty rigs, of many of the engineering refinements being proven in the smaller power rig. In addition to the improvements of surface drilling equipment, continued investigation of cementing practices and mud control will be required to meet the demands of deeper well completion. Although these two phases of the drilling operation have already received more than a fair share of investigation their importance can not be overemphasized.

Further application of mud ditch logging and core analysis will assist in determining completion methods which will require a minimum of time for the most efficient results. Inaccurate data on producing horizons often lead to poor completions and workovers which require additional rig time and added expense. The instruments used by the ditch logging service companies are of particular interest and will probably become standard equipment on all rigs. I refer in particular to the stroke counter on the slush pumps and the device for measuring the rate of penetration. The slush pump's stroke counter has saved a number of fishing jobs by indicating a wash-out in the drill pipe string before the driller could detect it on the mud pressure gauge. The rate of penetration is very useful in logging correctly the formations penetrated. Other improvements in technique and equipment may be expected.



(C) Ulric Meisel

Modern steam rig operating in Texas.

FACTS to Face in Future Drilling

By Ernest K. Parks

Petroleum Production Engineer

Some General Observations On Petroleum's Immediate Future

FUTURE drilling is something to be concerned about. This is no mere truism, so obvious to those who are actively in or associated with this phase of the petroleum industry. The steady continuance of oil and gas well drilling is vital to the welfare of the United States of America, notwithstanding our present abundance of current supply and reserves for the immediate future. Within the industry the maintenance of a stable business is the one great problem, and the stability of the drilling division is essential, for a structure is no more sound than its component parts.

Oil men, like other practical people, admit that self-preservation is the first law of nature. Stability is not desired for some altruistic reasons, it is required for survival. The fact that survival of the oil well drilling industry is in the public interest is a secondary consideration, but it is a good reason why the public should not interfere with the mechanism of the business. If the public will only take enough interest to see that its agents do not harrass and obstruct the petroleum industry, and will further concede that a fair living should be allowed those who have their lives and money in the enterprise, the industry will shoulder its own burdens and see to it that the citizens have gas, gasoline, and lubricants at a reasonable price so long as there is a supply to be had.

Few would contend that the supply of crude oil and natural gas, discovered and undiscovered, is inexhaustible, but there are those who concern themselves about the future for as much as 500 years hence. No one can talk sense about social, economic, and human needs five hundred years hence. If we are to be concerned about the public interest in the business of crude oil discovery and exploitation, this interest must be practical. One does not find even the most ardent conservationist riding a bicycle to save gasoline for future generations. In fact the petroleum industry should be much more concerned about the real long term outlet for its product than the public should be about a convenient supply.

The question is, then, what is the future of oil and gas well drilling over some immediate term of years long enough to warrant consideration and short enough to be practical? This indefinite but limited term of years is a variable depending upon the specific problem, but there are general facts of great interest.

In the year 1940 there were drilled in the United States of America 30,041 wells, of which 21,072 were producing oil wells. These are allocated by the A.P.I. as shown in the accompanying table 1.

TABLE 1

Well Completions

District	Total	Oil Producing	Percent Oil Producing
Eastern	13,281	9,057	68.2
Mid Continent	12,463	8,670	69.6
Gulf Coast	2,221	1,718	72.4
Rocky Mountains	1,046	768	73.5
East of California	29,011	20,213	69.8
California	1,030	859	83.2
Total U. S.	30,041	21,072	70.0

The fact that a well is not oil producing does not classify it as a dry-hole. There were some gas wells, and wells drilled for indirect production methods such as for water flooding or gas injection. Dry holes are not reported by the A.P.I. but are otherwise reported as 6786, or one dry hole for every 3.1 oil wells completed.

The footage drilled aggregated about 92 millions, giving an average per well of 3073 ft.

During the previous ten years ending with December 31, 1939, the A.P.I. reports show an average of 21,482 wells per year, of which 14,526 were producing oil wells. Of course the footage per well drilled is an important factor, but it remains much more constant than one would expect, in view of all the publicity of deep well drilling. Footage averaged 2940 ft. per well during the same period. Thus 1940 compared as shown in Table 2.

TABLE 2

Wells and Footage

Average per Year	Wells Completed Total	Wells Completed Oil Wells	Percent Oil Wells	Millions Feet of Footage	Footage per Well
Ten years prior 1940	21,482	14,526	67.5	63.2	2,940
Year 1940	30,041	21,072	70.0	22.2	3,073
Increase of 1940	8,559	6,546	2.5	29.0	133
1940 Increase, %	39.9	45.0	3.7	46	4.5

It should be noted that the increase in footage is a function of the number of wells drilled and the average footage per well. Expressed exactly the percentage increase in footage is:

$$100\left\{\frac{100+w}{100}\times\frac{100+a}{100}-1\right\}=f$$

where w = % increase in number of wells
a = % increase in average footage per well
f = % increase in total footage

Thus for the data of Table 2:

$$100\left\{\frac{100+39.9}{100}\times\frac{100+4.5}{100}-1\right\}=46\%$$ as quoted in the table.

For small increases one may approximate the percentage increase in total footage by merely adding the percentage increases for the number of wells and for the average footage per well.

This drilling of 92 million feet of hole in 1940 represents a vast business. There appears to be no recent authoritative estimate as to cost of drilling as applied to the entire United States and although not the product of extensive research it is here suggested that the cost may be $5.50 per foot. The use of such a figure results in a 1940 drilling cost of $507,000,000. With oil production for 1940 valued at the wells at 1,351 millions of dollars, drilling represents a re-investment of 507/1351 or 37½ percent of gross proceeds. With respect to earnings of the producing division the percentage of reinvested capital would be more than doubled. If operators were required by law to return some 75 percent of their annual earnings to sustain their business, this regulation would be considered drastic, unreasonable, and ruinous, yet oil men do so without legal compulsion, forced by necessity of preserving the continuity of the oil mining process.

There are those who contend that the present drilling is in itself ruinous, and that measures must be taken to curtail discovery and development of new fields. As a matter of fact drilling is curtailed. Compared to the number of wells

Diesel-electric rig drilling to approximately 12,000 ft.

which could be, and might otherwise be drilled, the present performance is mild indeed.

Whether we like it or not the social order is becoming more complex, and the people of this country are depending more and more upon the smooth functioning of industry. We are organized, and in any organization the subsidiary parts must operate in unison with one another. The petroleum industry is so huge that those who direct its affairs are forced to adopt a viewpoint leading to a broad policy of industrial welfare as against the long cherished individualistic conception of business enterprise. Oil men found this out long before there was any serious talk of governmental control. It may be quite true that the motive was self-preservation, but is it not far better to have an industry preserve itself rather than to attempt its preservation by governmental control and subsidy? The answer is "yes," and the proof is that now, in time of national emergency, the oil industry is the one great unit of fundamental supply which operates without a single worry to the defense administration.

The general public shows not the least concern over the oil business. As far as they are involved gasoline comes out of station pumps. The price is low; it is so low that despite constant reminders of the high tax paid on gasoline, directly and indirectly, the consumer cares not one whit. He travels on beautiful roads at over sixty miles per hour at better than sixteen miles to a gallon of gasoline, and is annoyed only that he must at times risk his life on a three lane highway.

In order to arouse the people as to the alleged need for government action the politicians stoop to the lowest form of instilling fear and suspicion into the public mind. There is talk of waste when there is no waste, of shortage when shortage is so far distant that one may as well be concerned about the shortage of salt, of mishandling of the business when the technique is the envy of the world. There are investigations, and threats, and administrative pressure to enact control legislation, but the drillers drill wells just the same and turn them over to the management to make a profit if possible.

Thus the drillers face a hostile government, an apathetic public, a distracted management, and in addition a competition which is at once the salvation and the despair of the oil industry. There is invested in the drilling department an unknown but great amount of capital. Some idea may be had by noting the number of rigs in the United States and giving them an average value to include auxiliary equipment. Thus for 4000 units at $50,000 per unit, the total is of the order of $200,000,000. Still more important is the number of men engaged in the work. There is no separate census of this division of oilfield labor, but again an approximation may be reached. At 5 men per tour (low for some operations, high for others) for three tours, there are 15 men involved for each rig. Allowing for 3000 active operations on full time basis there are 45,000 classified men per day. These men on a five day week raise the number involved to 45,000 multiplied by 7/5 or 63,000. To this must be added office force, warehousemen, mechanics, supervisory force, engineers, and management personnel. With a bare allowance of 5 percent for these the number is 66,150. With lay-offs, sickness, vacations, and other interruptions at 4 percent per year per man-year another 2,650 are added. The total is now nearly 69,000, which is estimated for the drilling group.

A rough check may be had by comparing the cost of drilling as divided into material and labor, but much labor is actually classed as cementing, shooting, or services in general. However, let a rough check be made.

An estimate based on inquiry from large operators plus collaboration with the American Petroleum Institute leads to an adoption of 25 percent of the annual wells drilled cost as the proportion for labor. Then with another approximation that the wells drilled cost is in fact the annual drilling bill we have 25 percent of 507 million dollars amounting to 126 million dollars. Using the personnel of 69,000 the result is $1800 per year per man. Such an annual income on a 50 week basis is $36 per week, which does not appear unreasonable.

As for the total of 69,000 employees, one may compare this estimate for drilling personnel with the total for crude petroleum production; that is, 119,305 wage earners and 9903 salaried employees in 1935.

Summarizing, the estimated data are shown in Table 3.

TABLE 3

Summary of Drilling Business Dimensions

Annual Wells Drilled	30,000
Wells Drilling	3,000
Employees	69,000
Annual Cost	$507,000,000
Investment	$200,000,000
For Wages and Salaries	$126,000,000
For Material and Services	$381,000,000

The 75 percent bill for other than labor involves dependent drilling supply sources representative of additional thousands of men and millions of dollars. Although there has been no detailed analysis, the American Petroleum Institute was able to furnish a few significant facts. Late figures are, of course, not available but for the year 1937 when 33,000 wells were completed, it has been estimated that 1,250,000 gross tons of oil-country tubular goods were produced for the industry. This alone was responsible for 80 million man-hours of labor, or enough to give 39,300 steel workers employment for 52 weeks. The pay roll was $60,000,000. Although not all this steel was used for drilling, there was, in addition, a large outlay for drilling machinery, engines and tools.

The 1939 census of manufacturers reveals significant details summarized in Table 4.

TABLE 4

Oil Field Machinery and Tools, 1939

Establishments	223
Salaried Personnel	2,538
Salaried Payroll	$6,644,051
Wage Earners	12,519
Wages	$18,740,996
Value of Products	$88,977,327

All this material requires a great organization for sales and the "Census of Distribution" for 1939 counted 1297 outlets doing a gross business of $259,151,000. The employees averaged 7427 with a total payroll of $13,565,000.

Notwithstanding the lack of actual segregation to drilling the census compilations give some idea of the range of size of the supply business supported in large part by drilling activity. A rough check would be to apportion the 75 percent of the total drilling cost for materials and services, between actual labor and basic supplies. The result would be, on the same basis as used to estimate drilling labor, 25 percent of $381,000,000 or $95,000,000 for labor and $286,000,000 for material.

A review shows that the census figures could be compared with the gross estimate as shown in Table 5.

TABLE 5

Drilling Cost for Materials and Services		$381,000,000
25 Percent for Labor		95,000,000
Steel Labor*	$60,000,000	
Oil, Machinery and Tools, Labor *	25,400,000	
Distribution Labor	13,600,000	
Total	$99,000,000	
75 Percent for Material		286,000,000
Value of Oil Machinery and Products from Census of Distribution	$259,000,000	

* Includes salaried payroll.

It is thus seen that the conservative estimate of $507,000,000 for 1940 drilling cost furnishes a base for labor and material which exceeds 100 percent of the quoted figures for the entire oil business. The drilling cost is deemed conservative in view of the direct method of estimating the total on a basis of dollars per foot drilled. Another estimate received on good authority quotes about $25,000 per completed well, resulting in an estimate of "between 700 and 750 millions of dollars." Obviously the census figures are sample statistics which are too small to be used for a real grand total for the industry.

In summary the annual drilling effort in the United States is thus seen to involve at a minimum a number of wage earners and salaried employees somewhat as shown in Table 6.

TABLE 6

Summary of Personnel Dependent Upon Drilling Activity

Directly Occupied in Drilling	69,000
Tubular Steel	33,000
Oil Field Machinery and Tools	25,400
Distribution to Oil Industry	7,400
Total	134,800

Contemplation of these figures will yield some appreciation of the necessity for stabilization of the nation's oil well drilling program. It must be realized that 135,000 employees are not useful unless organized. Furthermore the employees are skilled workmen, whose long training and experience can not be duplicated on short notice, as is now being proved by attempts to expand airplane production and machine tool output. Without further analysis, one may say that it would be disastrous to permit the nation to suspend drilling operations while current supplies are being used, and then expect a magical resumption of adequate drilling upon demand. Some price must be paid for stabilization. Violent interruptions are certain to be ultimately very expensive. Over-drilling will bring on some kind of dislocation. Regimentation is mere socialism. What kind of control is safe, sensible, and economic? The answer lies in self-regulation for profit.

An essential to regulation is a basis of facts. Great excitement in one particular locality does not indicate a state of the industry. Almost negligible activity in one area does not predict oil starvation. Drilling for and producing oil is a mining enterprise resting upon a geological foundation. The history of such raw material production is a series of local ups and downs but the broad view is the national outlook.

The petroleum production industry is already conducted on a national basis, notwithstanding local overproductions and depletions. National statistics are published weekly by the A.P.I., national monthly data are issued by the United States Bureau of Mines, national meetings of professional men in the American Association of Petroleum Geologists and the American Institute of Mining and Metallurgical Engineers consolidates information. Trade journals have universal circulation weekly and monthly. There is distinctly a national viewpoint, aided by the scope of the major operators who must conduct their operations with an objective to long term existence.

The back log of petroleum demand is well known, in quality and carefully analyzed quantity. There has been much statistical study of demand. Some selected estimates appear in Figure 1, which shows the source. Parsons and St. Clair published their data in MINING AND METALLURGY, April, 1937, p. 195, and H. A. Breakey of the U.S.B.M. supplied data through an unpublished report. The A.P.I. study was under the direction of F. VanCovern in 1935.

Just as in the case of gasoline stocks the supply on hand is in itself no true measure of its sufficiency. Long since the gasoline storage has been viewed as consisting of two components; working stock and days supply. We should adopt the same view as to crude oil. Some great percentage of reserves is necessary merely for maintenance of steady production. The available balance constitutes a term supply. Mere "millions of barrels of reserves" is not a significant figure.

The A.P.I. has just announced its estimate of U. S. Reserves as of January 1, 1941. They are 19,025 millions of barrels. It would be a contribution to knowledge to obtain a careful survey of reserves required to serve as sub-surface working stock, the portion deemed to be fairly difficult of extraction, and the very mobile reserve which could be considered almost as crude stock. The A.P.I. estimates are for "all grades of crude oil and distillate known to be recoverable under existing economic and operating conditions." Nevertheless one can not divide the reserve total by the consent rate of production of 1,351,847,000 bbls. and conclude that there is a 14 year supply on hand.

Drilling in 1940, plus revisions in estimates, resulted in the A.P.I. estimate of 1,893 millions of barrels as the increase last year. The addition exceeds production by 14 percent, but the excess is only in arithmetic. It will take from 10 to 25 years to produce the reserves discovered in 1940. The arithmetic becomes useful however, if the annual continuous reserve addition is equal to demand. This has happened often enough to bring about the idea that annual discovery and extensions providing reserves equal to the annual demand is equivalent to maintaining the years' supply.

Pumping wells in the hills southwest of Los Angeles; note the old type wooden derricks in the background.

Almost anyone could live in ease of mind if he knew that the next ten to fifteen years were secure. Very few of us have so little to worry about that the future supply of gasoline is of any concern. Supplies are, after all, not the sole solution. There has never been a fundamental shortage of steel, yet we are now short of ships. Just as fabrication is necessary in ship building so is time an essential fourth dimension in any petroleum supply equation. The petroleum industry has provided not only the supply but the time element as well. All needs to any emergency imaginable could be met at once, without restriction of use in any manner whatever.

Up to the present time the oil industry has borne

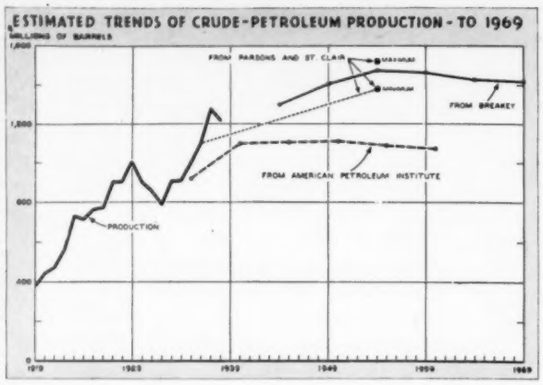


Figure I

its overload of preparedness from its own profits, which have been thereby reduced to an alarming extent. No claim is made for patriotic virtue, but oil men have been responsible to their social obligations. That is, they have held the business together and now the nation is the better off. The industry stands ready to continue and if, through such discussions as the present one, operators large and small may realize the importance of coordination the future may be faced with confidence.

Our present reserves are not unreasonable. They are adequate only in view of our phenomenal success in discovery. Discovery is essential to supply. Drilling is essential to discovery and to development. A little examination of a reserve supply will disclose its limitations, and some of its possibilities.

The composition of a reserve is of interest to the driller because it has a vital effect upon the upward economic limit, beyond which an over supply becomes a brake on further operations.

Oil wells drilled in 1875 are still producible. Oil wells drilled thirty years ago are still very much a part of current steady production. Wells ten years old are still capable of exceeding their allotments. This means that the reserve figure grows in such manner that there is a constantly increasing base of long lifed production.

However conscious the industry may be with respect to the necessity of maintaining reserves, it would be well to look at the practical side of the policy in the hope of discovering some limit beyond which there may be a tendency to break down the system which we have developed to control output. An analysis of reserves with respect to their composition could be of great value, but such a task is beyond the scope of this article. A preliminary examination of the problem will disclose to any student of the situation that:
1. The length of time that present reserves will produce the required daily output is a prime factor.

2. The average rate of decline of potential rate of reserve fields after declining below the current requirement is vital to estimation of usefulness of the reserve.

3. The relation between oil and gas involved in the reserves is necessary to an evaluation of their proper use.

4. The average settled production involved in the reserve is a valuable consideration in estimating their stability.

5. The cost of maintaining the reserve is of immense economic importance.

It is known, of course, that the building up of reserves generates an economic pressure to produce the oil regardless of demand. It is well known that the present pressure is such as to cause grave concern. It is further realized that the petroleum industry is intensely competitive within itself and the latest discovery may be made by a new company which requires production at once to continue in business. Therefore, while contributing to national security by discovering and developing sources of crude production, there is being approached some limit beyond which there will be a severe disturbance of the producing business. A thorough investigation of the reserve situation is warranted, and might be conducted by the A.P.I., the American Association of Petroleum Geologists, or the American Institute of Mining and Metallurgical Engineers (A.I.M.E.). A political investigation would be biased and wasteful.

An essential to reserves is the cost of drilling. Wildcat drilling is not subject to the same type of economy as is practiced in routine drilling and circumstances are so varied, and the practice so different that this phase has been ignored. But routine drilling bears detailed study.

Attention is called to reported cost of drilling in 1931 for various examples as shown in Table 7. One look at these values will convince those who are familiar with the respective localities that a great change has taken place. In order to get samples of drilling cost reduction several sizeable operators were interviewed and graciously submitted actual figures which are representative of the possibilities which have existed, and indicate that still more may be done to lower costs.

The first step in a determined program is find out the facts. Accurate and significant costs in field terms of definite character must be available at once, and not after operations have become a memory. This means that the field supervisor charged with cost responsibility should outline the cost analysis and see to it that field charges for time, material, and services are carefully described and allocated. He may have to arrange with his headquarters office to speed up evaluated invoices, and supply him with all costs not usually kept in the field.

TABLE 7

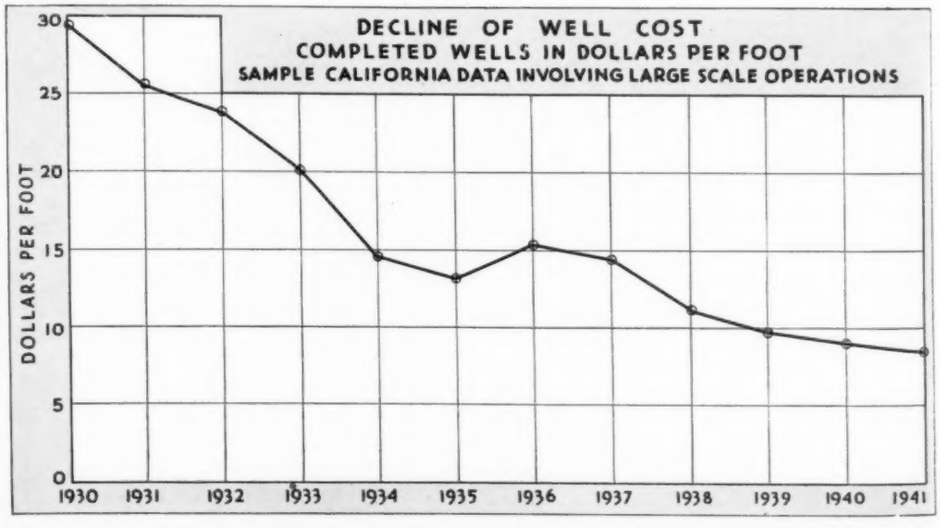
Cost of Drilling Wells to Producing Formations, 1931 *

Field or District	Depth of Well (feet)	Cost per Foot of Depth †
California		
Santa Fe Springs	8,200	$26.89
Kettleman Hills	7,694	32.40
Oklahoma		
Oklahoma City	6,650	18.45
Seminole	4,275	16.41
Texas		
Gulf Coast	6,000	10.60
East Texas	3,650	6.51
Hobbs, New Mexico	4,200	21.37
North and West Texas	3,500	10.80
Wyoming	3,000	10.98
Central Ohio and West Virginia	3,000	4.99
Bradford, Pennsylvania	1,650	2.22
Kansas and Oklahoma	850	3.13
Owensboro, Kentucky	750	3.51

* Data from H. C. Miller and B. E. Lindsley, "Report on Petroleum Development and Production," *Petroleum Investigation* (U. S. Congress, House of Representatives. Hearings on H. Res. 441, 73d Cong., Recess, 1934), part 2, p. 1158.
† Cost of pumping equipment is not included.

The cost analysis sheet should not be regarded as a permanently standardized segregation. Conditions change, and the cost figures must be alive with current information on operations in progress. Such costs are "operating costs," or "field cost control sheets," or "job costs." They are not accounting costs, and as such should not be kept or issued by so called accounting departments. The field supervisor is not interested in technical write-offs, special accounting classifications, S.E.C. rules, internal revenue regulation, and C.P.A. practice. These are necessary, and are for the accountants but job costs are for saving money now, and they must be simple, direct, and quickly available. This advice comes at every turn. There is urgent need for cost tools for the field, and management should see that they are supplied and used. Superintendents and responsible engineers who are actively accountable for expenditures should demand a cost

Figure II



system suitable to their needs, with due regard for the clerical cost involved. The clerical staff is not to be set up as a social security measure for employment relief, but like the drillers, the clerks and the cost systems are employed for the job as part of the job and when the need is over someone must see to it that the office practice is revamped to suit the new condition.

Three examples of remarkable success in cost reduction are shown. Two are for regular steam powered rigs, with one example of large scale operations and the other for a very moderate development. The third example is for electric drilling. The examples are not comparative as to choice of method. They are to illustrate that regardless of the method in use, or circumstances of the venture, costs may be reduced.

The first case of cost reduction applies to a large scale program involving some ten continuous strings of steam powered tools. The cost curve is shown in Figure 2. The wells involved are close to a 6000 ft. average depth. The number of completions involve from 60 to 80 per year, but the object of the curve is not to make a detailed analysis of all the factors. The curve simply shows results of technical skill and good management as applied to drilling.

In the year 1940 the same concern summarized all drilling expenses as shown in Table 8.

TABLE 8

Proportions of 100 Percent Drilling Expense for Principal Items

	Percentage
TANGIBLE MATERIAL	
Development Expense (casing, fittings, etc.)	36.10
Producing Equipment	4.81
Total	40.91
INTANGIBLES	
Labor in Construction and Drilling	15.75
Services Contracted	5.64
Fuel and Power	5.55
Repairs and Supplies	2.83
Trucking	3.42
Total	33.19
OVERHEAD	
Drilling Tool Rental	21.86
Superintendence and Miscellaneous	4.04
Total	25.90

In segregating these costs as between actual material and labor it works out that the ratio is close to 75 percent and 25 percent respectively. This ratio appears to be the commonly accepted distribution.

Inquiry as to ways and means of making the remarkable cost reduction disclosed that technique accounted for greater speed by controlled drilling procedures, reduced mud costs, bit savings, and drill pipe economies. Management or superintendence accounted for reduced construction, fewer days rigging up time, faster moving between locations, and general direction of the cost control program. Petroleum engineering revised the casing programs, and it is in this respect that further reductions are anticipated.

The casing program variations, looking toward saving steel, plus reduction in required sizes of rig and drill pipe, and economies in actual drilling operation is a subject to be separately treated. All operators can not be expected to follow the most recent and most spectacular slim hole practice, because oil fields differ and circumstances may not be at all comparable. Some anticipated savings with decreased diameter wells do not materialize because only part of the routine and equipment is adjusted to the new program. Other plans involve alternative procedures which are almost equal the savings of the revised method. Finally, there is the future to consider. A well is to serve for a long time, especially in view of pro-rata production. The producing department engineers should have a voice in the matter.

Assuming good coordination, flexibility of the development program, the entire drilling process, and production probabilities with respect to the well equipment and reservoir behavior intelligent reductions in well investment may be made. It appears that the combination water string and oil string is firmly in the minds of operators as a means of economy. California practice has long adhered to the plan of obtaining a separate and independent water shut-off, but the precedent has already been broken and the combination method will increase in application.

Time and motion-study is being applied to tearing out, moving rigs, and rigging up. In this work portability is a relative term. The size of boiler plants, draw-works, and mud-pump units which are being moved about with ease and at a saving merely illustrates that technique must be fitted to the conditions. Wherever the drilling there is opportunity for better ways of doing things, but someone must be making a systematic analysis of the present motions and equipment before better ones can be substituted. There is no doubt now that oil field operations have passed the happy-go-lucky stage. Whereas it was once satisfactory merely to get the job well done, it must now be well done efficiently.

Derricks are coming down. This is no news to many, but is still to be appreciated as an economy measure by others. Sub-structure is being simplified. Steel is replacing cumbersome concrete. No one is blamed for past practice. The change is merely an adaptation to new conditions and a product of experience.

Standardization with all its strides still presents opportunity as especially well illustrated in moving rigs, and providing portable sub-structures, pipe racks, and boiler settings. Pieces of equipment are handled once. It is only common sense to plan where one is to place an object before he picks it up, but such simple philosophy has not always been observed.

Mechanically the industry is still much indebted to the suppliers. The list of aids is too well known to warrant discussion, and still grows. Bulk cementing, continuous mud analysis, field laboratory service for core analysis, and accurate thermometric surveys are already more or less familiar additions to commercially available assistance.

Application of items which have been discussed was successful in causing the cost reduction shown in Figure 3. Here is an example of economy in small scale work of a routine nature, proving that it is not only the wholesale exploiter who may profit by attention to what goes on in the field.

On this series of operations there was a one string steam power program covering the drilling of 17 wells to a depth of close to 7300 ft. each. After the discovery well, there was some further exploration and experimentation required and a cost basis was not established until the fifth well, drilled in 1938. This cost was $12.20 per foot, including production equipment and required 74 days to drill. Earlier wells cost as much as $16.00 per foot but are not representative of routine operations, which were examined in detail as soon as practicable with the results shown in Table 9.

This operator, who so ably reduced costs with his steam powered rigs, has come to the conclusion that steam is not necessary to his drilling requirements. He uses no more steam. Instead he has adopted gas engine power with outstanding

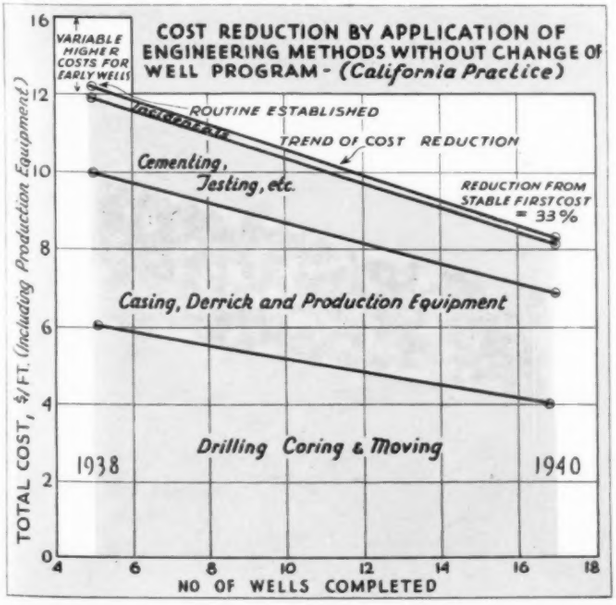


Figure III

success. This move is very significant, coming from one who has spent years working down costs of steam powered rigs.

TABLE 9

Item	5th Well 1938 Cost per Foot	17th Well 1940 Cost per Foot
Fishing and Emergencies	$0.30	$0.10
Cementing, Testing, Power, Water, Supplies	1.90	1.10
Drilling, Coring, Rigging Up, Tearing Out	6.10	3.90
Derricks, Casing, and Production Equipment	3.90	3.10
	$12.20	$8.20

Gas engines are preferred in this case because:

1. They power the rig for a total power cost which would pay only the fireman on a steam rig.
2. They eliminate the boiler plant, and the moving of that plant.
3. They make valuable gas available for sale.
4. They eliminate the necessity for arranging for large water and gas supply, and the required lines to furnish these usual necessities in quantity.

The investment in a drilling rig completely powered with gas engines is slightly more than for a steam rig, and the operator making the change has some equipment to dispose of, but this has been taken into consideration. Furthermore so convinced is he that his solution is the most economic that he will not entertain contractor's bids unless they propose to drill with gas engines. "Why," he asks, "should I furnish a large water supply and great quantities of gas for a steam plant when I know that gas engines of adequate capacity, properly connected and intelligently maintained, will do the same work for less money?"

He is not alone in this view. Others who direct major campaigns are coming to the same conclusion, and it may be anticipated that in the very near future the lowly "spark plug" intruder will have become a distinguished member of the drilling power group, just as has long been the case in production power. This displacement of steam will not be sudden, but it will be persistent.

Coupled with the gas engine progress is power transmission, clutch improvement, and draw works design in general. Such new designs are slow to make their appearance but they are in use, and as the old order goes into retirement the new will be seen.

Steam is by no means threatened with extinction. There is back of steam a long tradition, a huge investment, a familiar technique, and a great success. Ahead there is competition with cost control, deep wells to drill, and steam engineering with two hundred years of experience. Continental Oil Company has a most modern plant operating in California. A marine type, water-tube boiler installation, with super heaters, evaporated water supply and condensers, delivers metered steam at 350 lbs. psi. The plant will be a point of interest to A.P.I. visitors to California this fall.

Electricity is not to be ignored. It too has made an inroad into the drilling power field. Two California companies who use electric power in routine development drilling were consulted. One still uses steam for mud pumps, but the other powers the entire rig with electric motors. Here too savings have been made by watching the details.

In this case there were involved 32 wells to about 3200 ft., drilled consecutively with a one string crew in a California developed field. The cost was cut 50 percent in three years' time. There was no change in the casing program, which was simple with only a water shut-off casing and a liner. The greatest savings here were in drilling time, and in moving time. The latter being cut from seven days to four days. A well crew now drills the first 3000 ft. in four and a half days, and a typical well cost is $12,500, split up as shown in Table 10.

TABLE 10

Well Cost Distribution, Shallow California Electric Drilled Hole

	Cost	Percent
Tangible Equipment, Casing, etc.	$4,100	32.8
Labor	3,250	26.0
Tool Rental	1,500	12.0
Miscellaneous	3,650	29.2
Total	$12,500	100.0
Cost per Foot	$3.90	

Costs, of course, are not of specific value, unless the details and circumstances are known. Nevertheless, here is a case where economy was essential and by good engineering management the savings amounted to a sizeable sum; not $12,500 per well to be sure, but probably in excess of $150,000 for the enterprise.

The savings were accomplished by time and method studies, by unitizing the draw-works, and by the use of second hand material where practicable. Electric power was used throughout the program. Small items, often ignored, were not overlooked.

As for electric drilling, generally, L. S. Peterman, petroleum specialist, Southern California Edison Company, Los Angeles, says:

"There are many advantages in the use of electrical power for drilling oil wells which are briefly as follows:

"1. Low operating cost. Records from actual installations show that electric power is much less costly than steam power for a rig of comparable size and drilling under the same conditions.

"2. Maintenance costs are extremely low.

"3. Moving and set-up time are short and therefore, the cost of moving an electric rig is much lower than a steam rig of corresponding size.

"4. The life of the equipment is extremely long. There are many electric rigs in operation in California and other fields which are 12 to 15 years old and are still in daily operation.

"5. Capital investments are reasonable although they may be somewhat higher than in the case of a steam equipment. However, the low cost of maintenance, operating cost, and the saving due to short set-up time, and cost of moving, quickly offset the difference in capital investment. The main reason for the higher cost of A-C electrical drilling rigs is due to the high cost of power pumps. It is hoped that recent developments will result in new types of mud pumps which will materially reduce the cost of power pumps."

He continues with reference to rotary drilling with direct-current equipment: "One of the most successful developments in electric drive for rotary drilling and mud pump operation is the application of D-C motors operated by generator voltage control from engine-driven generators or motor generator sets.

"A D-C rotary drilling equipment usually consists of two or three duplicate generators with direct connected exciters, driven by duplicate internal combustion engines or by an A-C motor, one or two motors for driving the drawworks, two motors for the mud pumps and suitable control and protective equipment. One generator supplies power to the draw works for rotating the drill pipe during the drilling, and the other at the same time supplies power to one of the mud pump motors. When it is necessary to withdraw the drill pipe and bit from the hole, the mud pump is shut down and the power from the two generators is combined to supply the heavy demand from the draw works motor."

Although more description is offered than space permits quoting, the features are summarized.

"The following is a summary of the advantages of D-C drilling equipment from the standpoint of the operating engineer.

"a. Its characteristics are so designed that it is impossible to impose loads on prime movers greater than they can carry, thus definitely preventing their being stalled.

"b. It has speed characteristics like the steam engine, thus giving a wide range in speed and torque for the draw works and a positive indication of any restriction or stoppage in the mud pump line.

"c. It makes available the combined capacity of the mud pump and draw works power supply for heavy hoisting duty when coming out of and going into the hole.

"d. It provides individual control of drilling and mud pump operations, centralizing this control at the driller's stand.

"e. It readily provides low table speeds, quick reversals, fast or slow pick-up as required on heavy or light loads, and speeds of the empty hook as high as the crew can handle."

Data are given by Peterman to show some power cost results of California electric drilling. This information is given in detail in Table 11.

TABLE 11

Records Obtained from Montebello Field (California)—Three Wells Drilled

CONNECTED ELECTRIC LOAD:

2—150 HP motors on drawworks
2—150 HP motors on 7¾" x 16" pumps
1—250 HP motor on 7¾" x 16" pump
1—5 HP motor on blower
2—3 HP motors on mud screens
1—15 HP motor on desander
1—3 HP motor on water booster pump
1—12 KW air heater
8 Kilowatts in lighting.
Total connected HP—906

Miscellaneous Data:

Well Depths: 7598, 7610, 7603
Total Footage: 22,811
Total Elapsed Time, including all erection and dismantling of 3 installations—149 days.

COST ITEMS:

	Total Costs
Installation and removal costs of Edison Company facilities	$1,800.00
Metered energy 549,800 KWHrs.	6,168.94
Lighting energy included	
Total electric costs	$7,968.94
Average Unit Costs	
Per KWH	$00.01449
Per Day	53.49
Per Foot	00.35

In connection with studies which are currently conducted in order to maintain economic cost control an interesting set of data were collected involving the drilling of a recently completed well, with gas engine equipment, to a depth of 7400 ft. in 91 days. It is realized that this segregation is not directly comparable to others without additional details, but nevertheless the time allocation illustrates typical requirements and may be useful when converted to some desired percentage basis. As an example in Table 12 it is seen that repairs amounted to only 4.8 percent of the total time, and that the bit was on bottom almost 42 percent of the time. It may be appropriate to remark at this point that although it is commendable to increase the percentage time on bottom much can be done to increase the effectiveness of the bit while it is on bottom.

TABLE 12

Item	Number of Days
Drilling bit on bottom of well	38
Total "dead" time	38.2
Running into hole	6.6
Pulling out	8.7
Circulating	4.3
Surveying	1.8
Making connections	0.9
Pulling cores	2.7
Total time out of hole	13.2
Lost Time	14.7
Repairs	4.4
Fishing	10.3
GRAND TOTAL TIME	90.9

Discussions with operators relative to the maintenance of experienced drilling crews and to the drilling tool inventory disclosed that the contractor fulfills an important place as a stabilizing influence in oil well drilling. The contractor makes it unnecessary for operators to keep up maximum establishments or periodically and violently to increase or decrease their personnel and drilling rig machinery. The larger operators depend upon the contractor to absorb the peak loads and it appears to be the lot of the contractor to handle this business when and where it appears. For this service the operator should be willing to pay, for it definitely saves him very great expense which heretofore was simply a part of the drilling cost. It has recently been stated that the drilling contractor is entitled to a profit. No one expects the contractor to drill without profit notwithstanding that the bidding system sometimes cuts very deeply into the available margin. An interview with one operator who pointed out the money saving utility of the contractor stated that "he must have a reasonable profit because he must be kept in existence." The contractor's view solicited from the American Association of Oilwell Drilling Contractors is formulated by their well known secretary, Brad Mills, in the following quotation:

(C) *Ulric Meisel*

"From 20,000 to 31,000 wells are annually drilled for oil and gas in the United States, and it is not reasonable to suppose that drilling operations will 'dry up' because of unsettled world conditions. Drilling should continue at somewhere near a normal rate in most of the large oil producing areas.

"The search for new reserves will continue, and systematic development of new fields will be carried out. Scenes of intensive activity will shift, but drilling operations must continue because of lease requirements and the necessity for maintenance of adequate developed oil reserves. A virtual stoppage of drilling operations to permit current petroleum demands to approach developed potentials would do vastly more harm than good. Of course, such a plan is not contemplated, and the fact that United States fields could produce overnight much more than current needs is a healthy condition in this time of uncertainty."

NEW CYCLE OF PETROLEUM E

Various Factors Contributing to Enlarged Campaign for Expansion of Reserves—Movements Worked by Judicious Combination of Established Methods—Some New Variations.

By Joseph L. Adler
Independent Exploration Company

THE first quarter of 1941 has produced definite evidences that a new cycle of exploration for petroleum is under way. This development has not been entirely unexpected; several indications during the last two years presaged the current activity. New territory was taken into the sphere of operations, new exploration methods were tried out, and methods which had been relegated to only occasional or special use were restored to general practice. These departures from routine exploration appear to have been more than sporadic deviations from the beaten path. There is evidence that they may have initiated a concerted campaign to expand petroleum reserves in the United States and Canada.

As recently as 1938 a considerable number of active producing companies hesitated to venture even into such territory as Illinois, Indiana and Mississippi. The geologists charged with the determination of their exploration policy readily admitted that their hesitation was based on the fear that those areas were too wildcat, too far from the well established producing districts of the country. They maintained this attitude in spite of the fact that Mississippi bordered immediately upon the prolificly productive state of Louisiana, and despite the well-known history of Illinois, where earlier in the century the shallow pay sands around the bare edges of the Illinois basin had made it the leading oil producing state of the Union. But today we see these same companies preparing, or even prosecuting, large scale exploration campaigns in such areas as North and South Dakota, Nebraska, Alabama, Florida, Georgia, Tennessee, Saskatchewan, eastern Ohio, and northern California.

The potentialities of these areas for oil production cannot be seriously denied. But on the basis of past history none of them offer the degree of encouragement to the oil producer which was offered to these same hesitant operators by Illinois, Indiana and Mississippi from three to five years ago. The new cycle promises to be more adventurous than the old.

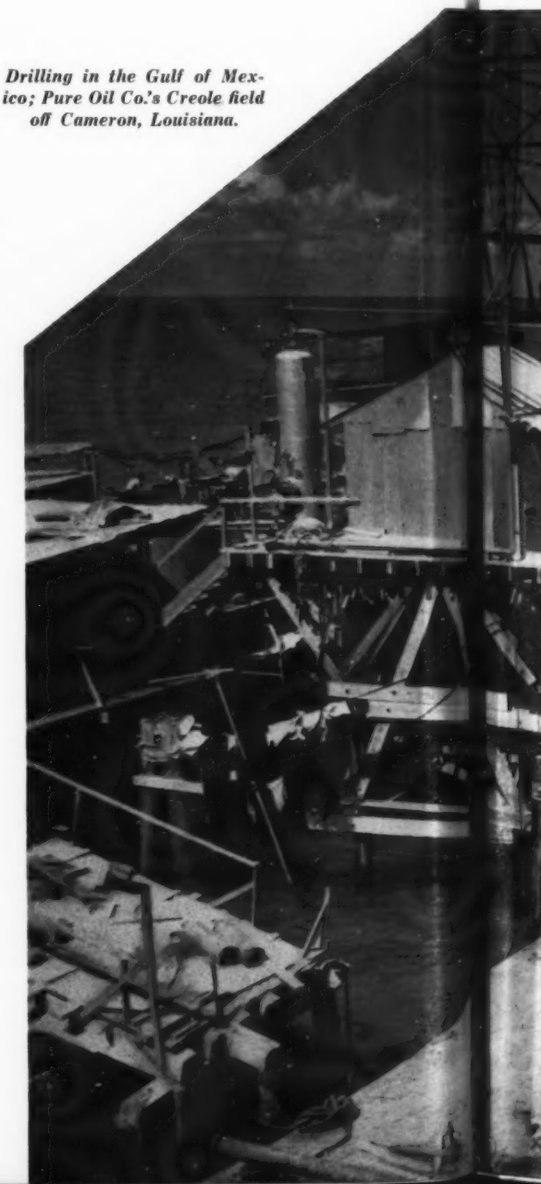
The general revival of older methods of exploration embraces surface geology, shallow sub-soil sampling, core-drilling, magnetic, electrical, and gravitational methods. Seismic exploration which had been on the decline for the past three years has shown a marked upturn during the first four months of 1941. Soil hydrocarbon analysis, chemical well-logging and gamma-ray logging have passed through their preliminary experimental stages and may be expected to find their places in surface prospecting and subsurface correlation in the new exploration campaign. Electrical well logging and petrological and paleontological examinations, however, will probably maintain their present position as the principal well correlation tools. Another new method not yet applied extensively which holds promise as a correlative of shallow subsoil sampling is vegetable ash analysis of which more will be said later.

It is natural to look for the causes of such a marked change in the petroleum exploration situation. Indeed, unless sufficient reason for the initiation of a new cycle can be shown, the oil industry will be justifiably skeptical of the permanence of the new attitude. Even during years when exploration has been near the minimum of the past decade, occasional brief interludes of activity have occurred. At present, however, there appears to be a greater number of factors contributing to the revival of activity than at any time during recent years. We shall briefly review them here.

The only discovery of major importance east of the Rocky Mountains in the past ten years was the Illinois-Indiana Basin. That decade was initiated by the discovery of the Conroe and Oklahoma City fields, following very shortly on the discovery of the East Texas oil field. The effect of the flush production from these large fields, plus the conviction that exploration along the trends on which they lay would supply a tremendous quantity of oil reserves from the viewpoint of the depression demand then used as a yardstick, served as a very effective brake on exploration at that time. But proration soon restrained the excess production and the trends proved to be a myth, so that by the middle of the decade a healthy exploration program was beginning.

Unfortunately in one way for that large contingent of the oil producing industry which is entirely dependent upon exploration, the discoveries in the Illinois-Indiana Basin resulted almost immediately from this activity. The retarding effect which the discoveries in that district had upon the development of the oil industry in other parts of the country was accentuated by the simultaneous occurrence of the so-called business recession. The new cycle may be said to have received its initial impulse from the realization that the flush production in Illinois and Indiana, without benefit of proration, would be short-lived. The prompt fulfilment of this prophecy by the declining Illinois production figures at the end of 1940 has given additional impetus to the current upward movement in exploration.

In another way Illinois and Indiana have contributed to at least one phase of the new program. The development of these fields brought home to the small producer and wildcatter a fact which previously had been more familiar to the integrated companies, namely, the advantage of securing ample production in regions near the retail market. In either Oklahoma or Texas an unrestricted flood of oil such as the last few years have witnessed in southern Illinois and Indiana would certainly have demoralized the local market. The large market of the northeastern states, however, readily absorbed the Illinois-Indiana production, despite the lack of proper transportation facilities. The extension of large scale exploration to other areas with substantial markets



Drilling in the Gulf of Mexico; Pure Oil Co.'s Creole field off Cameron, Louisiana.

and little or no production can be attributed in part to a realization of the advantages of discoveries in such areas. Eastern Ohio and the southeastern states are cases in point.

Restriction of foreign markets as a result of the European and Asiatic wars has caused a corresponding restriction in foreign exploration. This situation has released funds and personnel, and to some extent materials, for exploration at home. While this condition has existed for nearly two years, a corollary situation has recently arisen from the same causes which has already made its beneficial influence felt in domestic exploration. That is the so-called defense movement, with the resultant increase in petroleum demand produced by the stimulation of general business activity. It can readily be seen that here is an influence whose dimensions will grow as the defense movement progresses, and if Great Britain should be cut off entirely from her Asiatic oil supplies, the demand for American oil is likely to exceed all expectations.

Crude oil prices already have risen as a direct result of this influence. This reaction has gone a long way toward allaying the fear the increased demand would be met simply by the increase of allowables. Even such a solution, however, would so augment the income of the producers as to make more funds available for exploration. That the average producer prefers to spend a large proportion of increased profits on exploration, with the hope of expanding his petroleum reserves, rather than to pay out part or all of the added increment in income taxes and surplus profits taxes, has always been recognized as a large controlling factor in the volume of exploration.

The defense situation also accelerates the pace of the new exploration program for another reason, which is one of the few indications that augur ill for a prolonged campaign. It is feared by many that in the not distant future the needs of national defense may deprive the producing industry of certain materials essential to the prosecution of intensive prospecting. Among these are pipe, drilling tools and engines, electrical equipment, explosives, and numerous other items. Indeed the Selective Service demands have already deprived the industry of a substantial part of their younger trained personnel. The petroleum producing industry can scarcely place its needs in this respect before those of other branches of the national defense, because it is obvious that the enlargement of allowables will permit the industry to supply all the oil that could be needed for many years to come.

But the experienced oil executive realizes that such an expansion of production combined with a restriction of exploration would inevitably lead to a period of panic caused by a real or imagined shortage of oil reserves after the national emergency had ended. Under those conditions exploration would be expensive and competition, especially in leasing, would be intense. For this reason many producers have initiated extensive prospecting programs this year, in order, if possible, to assure themselves of reserves ample to tide them over both the period of restriction which is feared and the costly period of frenzied exploration which might follow.

Turning from the causes which have set the new cycle in motion, it is fitting to discover the course that it is taking from the technical point of view. Methods of exploration properly vary from one region to another and different methods are applicable to different problems in the same region. Therefore the questions one commonly hears, "Has the reflection seismograph or the gravimeter, etc., about exhausted its possibilities?" or "Is slim-hole drilling or soil analysis the exploration method of the future, or will we have to find a new method?" can only be answered by a simple, "No."

The oldest method of exploration, random wildcat drilling, is still in use and is subsidized by major oil companies although rarely indulged in for their own account. So long as this type of exploration is continued, it will produce an occasional discovery. While such finds may be expected to represent a small part of the total discoveries numerically, who can say that some of them may not be among the most important with respect to size? But, of course, the judicious wildcatter foregoes this expensive procedure in cases where geological conditions offer the opportunity to make well locations by a more scientific procedure.

Surface geology is being used in certain areas where more exact differentiation of the outcropping section since the last time the regions were worked by petroleum geologists enables the latter now to delineate the less prominent structural features. In some cases the intensive microscopic study of well samples during the past twenty years has contributed largely to these finer differentiations. In areas where sufficient outcrops occur the surface geological work can be done with very little equipment, as for example in the Appalachian Basin, the uplands of the Gulf and Atlantic Coastal Plain states, locally in the western part of the Dakotas, in northwest

Texas and the southwestern and Rocky Mountain states generally. However it is in the regions where substantial but not insurmountable difficulties stand in the way of surface geological work that we can expect to find the greatest number of previously undiscovered structures by this means.

In regions where the shallower sediments are unconsolidated and thus subject to having their distinctive characteristics obliterated by weathering and cultivation, shallow subsoil sampling with soil augers and compilation of data on shallow water wells is being used in conjunction with surface geology. The lowlands of the Gulf Coastal Plain are an example of an area in which this procedure is in use. Surface geology is also used in new areas where no considerable amount of drilling has been done to determine regionally the character of the sediments as an indication of their possible value as sources or reservoirs of oil. The surface aspect of formations, however, is a dangerous criterion of their character at depth; for those formations which maintain for long distances at depth the same characters that they have at the outcrop are noteworthy as exceptions valuable for correlation purposes rather than as illustrations of a rule.

Wherever relatively thin covers of unconformable strata overlie the oil bearing series and have suffered little or no disturbance by the structure producing forces, core-drilling can be used to some advantage. Its use is definitely increasing in all the regions to which these conditions apply. The practical limitation is largely one of the depth below which a reasonable amount of structural conformity can be expected. In most cases core drills are not being used as a general prospecting method below a depth of a thousand feet, but exceptions are numerous.

As the depth of this type of drilling increases it is becoming the fashion to refer to it as slim-hole drilling, in which technique less emphasis is laid on cores and more reliance is placed in electrical logs, cuttings, and in some recent cases, chemical logs. Two or three years ago a great deal of slim-hole drilling was prognosticated by many oil geologists in their forecasts of the exploration methods of the future. This extensive use of the method has so far failed to materialize. One of the chief valid reasons for this failure is the difficulty in securing rigs for the purpose whose portability is anywhere near comparable to the portability of the standard shallow core-drills, although a great many other rather captious arguments are heard. In the development of complex producing structures where a large amount of structural information is needed to locate the position of the oil sands, however, the slim-hole is finding a very useful place. In connection with regional seismic work it is being used to advantage to establish points of control.

Magnetic methods of prospecting were brought into the new cycle of exploration very early because of their proved efficiency in obtaining certain types of information in northern Louisiana and Mississippi. In that district not only is the magnetometer effective in forming a picture of the depth of the crystalline basement, but it may also be used for locating many of the basic igneous intrusions which penetrate the sediments of the area and produce anticlinal structures. On the whole the extension of this method to Alabama, Georgia, and Florida has proved disappointing; but that is to be expected because in such areas the lack of any considerable amount of sub-surface information obtained by drilling makes the interpretation of magnetic data difficult. As more information accumulates in the form of well logs, more use will be found for the magnetic information.

The classical use of the magnetometer in petroleum exploration as an indicator of the depth of a shallow crystalline basement has also been proving useful recently in northern Texas, both east and west, in Nebraska, Illinois, Indiana and other areas. But refinements of magnetic data may be obtained by covering areas in detail and then removing the regional effects from the picture. Thus, in areas where the normal surface formations are concealed by thin overburdens of weathering products, alluvial deposits, or glacial drift, slight differences in magnetic permeability of the successive outcrop zones may be determined in many cases. The subsoil outcrops of certain horizons can be traced in that way and their interruption by faults, or their inflection by anticlines, synclines, and structural noses can be detected. This differentiation between slight distinctions in magnetic permeability can be carried even further in some cases, as for example in the case of shallow salt domes where the contact of the salt and the sediments lies sufficiently near a parallel to the lines of force in the earth's magnetic field. This is, of course, a very special condition but it is an illustration of the extent to which the use of the magnetometer may go. These more precise magnetic methods have been dubbed with the rather unenlightening name of "micromagnetic surveys." Their use in conjunction with surface or areal geology is now receiving proper recognition.

The revival of electrical prospecting at the earth's surface is partly due to the determination of the geophysicist not to neglect the hidden possibilities of any method which had been largely superseded in the early days of geophysical exploration for petroleum by the methods which are now considered standard. The chief stimulus, however, was given by the improvement of the electrical transient method through the application to it of the cathode ray oscillograph.

This combination eliminates a great deal of the frequent shifting of electrodes and the slow visual recording methods of the older direct current prospecting technique. But while the increased speed of operation has encouraged an expansion of experimentation with electrical surveys, no results of importance have yet been generally recognized. It is therefore difficult to say what role electrical surveys will play in the new cycle. It is probable that after twenty years of occasional use in petroleum exploration, the surface electrical survey will still remain restricted to the solution of a few special problems.

It is well known that the revival of gravitational prospecting is due to the invention of several excellent gravimeters, which, due to the speed of operation as compared with the torsion balance formerly used, enable the geophysicists to measure the values of gravity over a large expanse of territory at a sufficient number of points to obtain a complete and final gravitational picture of any given area at a very low cost. These intensive gravimeter surveys have indicated the association of weak gravity anomalies with structural disturbances so slight that it is difficult to explain the connection. This empirical relationship, however, is based on a sufficient number of cases to justify the use of the gravimeter for blanket surveys of well developed petroliferous regions in search of possible structures previously overlooked, as well as regional surveys of the new areas of interest to select the most promising locations for detail work by more refined and generally more costly methods such as seismic prospecting, core-drilling, and soil analysis.

The resurgence of gravitational exploration is not a very recent development, and because of the speed of gravimeter operation, large areas have already been covered by so many different companies that it is remarkable that any further gravity surveying should be done in them. But in the earlier gravimeter work the operators did not appreciate the necessity for extreme detail to locate weak anomalies caused by near surface variations of structural significance such as faults, possibly compaction and rarefaction of sediments and effects of slight erosion on imperceptible uplifts. Hence, considering the low cost of gravimeter work, the newcomer in an area prefers to obtain a new picture made in sufficient detail rather than to spend his efforts on the reinterpretation of less detailed data secured in an earlier day. Therefore, gravimeter surveys continue to play a large role in the exploration of old productive regions as well as in the more adventurous territories as the expanding program of new exploration gets under way.

Seismic exploration may be said today to fall into three distinct classes: (1) detailing old prospects or anomalies discovered by less refined methods or by earlier seismic reconnaissance; (2) evaluating blocks of acreage too small to be properly evaluated by less refined methods; and (3) making regional surveys where immediate financial return need not be the objective. In elaboration of the third classification it should be pointed out that a major oil company, determined

to make an exhaustive study of a certain district, can well afford to start out with a blanket seismic survey, in the certain conviction that it will end by making such a survey no matter what method it may use at the start. On the other hand small companies, syndicates, and individual operators generally want their ventures in a new district to be placed on a paying basis as soon as possible, frequently because they know that if that cannot be accomplished the venture will have to be dropped as a failure. Under such conditions the use of a more economical method for the selection of the most likely prospects, and the subsequent use of the seismograph or occasionally some other method for detailing and selecting among those prospects, before drilling a test well, is likely to yield the quickest financial return.

In certain areas where the density of dry holes is so great that there is only room for very small producing areas between them, seismic prospecting of those intervening areas is done with very great accuracy by utilizing the old wells as control points for the correction of velocities and the stratigraphic section. An extension of this method of operation involves the drilling of slim-holes at intervals for the specific purpose of obtaining control on stratigraphy and velocities in seismic operations. This combination of drilling and seismic prospecting offers the greatest promise for the discovery of stratigraphic traps. By combining carefully information on the thinning of reservoir beds shown by the slim-holes with the convergence of reflecting horizons and details of their structural attitude indicated by the seismic measurements, the location of test wells for the discovery of stratigraphic traps should be narrowed down very closely.

All the types of seismic reflection exploration mentioned are in active use today and occasionally even refraction work finds some special application. It is apparent that the seismograph will continue to be an indispensable tool in the new exploration cycle.

The newest methods of exploration for petroleum are those involving chemical analysis. A real interest in these methods did not develop in the United States until about five years ago, although they had been tried before then in Europe, notably in Russia. Various methods for detecting minute traces of hydrocarbons have been devised, some depending on analysis of gases exhausted from the soil by suction, others requiring the removal of soil samples or deep well samples to the laboratory where adsorbed hydrocarbons may be separated from the mineral particles, and still others relying on the concentrating effect of evaporation on the surface of the ground to produce a waxy residue which is measured in the laboratory.

The actual significance of surface or near-surface accumulations of hydrocarbons is subject to considerable interpretation but it is gradually being conceded that there is a direct connection between many such accumulations and bodies of petroleum and natural gas at depth. An even more marked relationship between commercial accumulations of oil and traces of hydrocarbons in the few hundred feet of strata immediately overlying them or adjacent to them laterally has led to extensive use of chemical well-logging. This procedure is useful to avoid the abandonment of a well just short of a possible producing sand, or the abandonment of a prospect due to a dry hole drilled just outside of the limits of future production.

On the whole, soil analysis is still considered too expensive for blanket surveys. The reason for this widespread opinion is that the local accumulations of high hydrocarbon content are not spread out over an entire prospective oil producing area, but occur rather in the form of restricted spots scattered over and around the area. Whether or not these spots are always grouped in halos as some geochemists believe, or whether the halos are merely a product of the fact that any random group of spots may be assembled into halos if sufficient irregularity in the contour of the halos is permitted, a well located in the center of the group of spots or of the halo, if that interpretation is preferred, is likely to tap the source of the hydrocarbons if the path of their migration to the surface is anywhere near vertical. But since the hydrocarbon spots are so restricted, it is necessary to take samples close together in order not to miss all or most of the high spots completely. It is this fact which, in the opinion of most oil producers makes the cost of a blanket soil hydrocarbon survey prohibitive. In checking the relative merits of prospects detected by other methods of exploration, however, the soil hydrocarbon survey promises to form an integral part of the new exploration program. This is particularly true where the possible presence of stratigraphic traps is indicated by subsurface information.

A new departure in chemical surveying has recently been suggested as an adjunct to areal geology. That is the analysis of the ash of various plants to determine the proportion of the basic elements which they contain. Certain plants tend to concentrate particular elements in their own tissues when traces of such elements exist in the soil in which the plants grow. Therefore when small quantities of certain elements are present in certain formations, the formations may be identified by the presence of those elements in the ash of plants which grew upon them, even though the formations themselves are buried under a considerable overburden of soil.

Aerial photographs as a method in the interpretation of surface geology have also been enhanced in value recently by the development of emulsions and filters which make possible the recording from great altitudes of color differences and other details not visible to the unaided eye. There is reason to believe that further progress can be made in this field from the standpoint both of recording and interpretation. It should prove a useful tool in the new cycle of exploration.

Electrical well-logging, gamma-ray logging, paleontological and mineralogical examination of well-cuttings and cores are, of course, all-important in correlation from one well to another and therefore continue to represent the bulk of the geological work done in areas where wells are plentiful. In the new prospective districts, however, this type of data can scarcely yield information comparable in value to that obtained from it in well developed areas. This is particularly true of electrical well-logging, in which art the interpretation of the records is pretty largely an empirical matter dependent upon previous experience in the district. Nevertheless this type of data must and will be obtained in most of the wells drilled in the new territories in order to accumulate sufficient data to make them useful in the future.

Perhaps the reader feels a sense of disappointment that no radical changes in exploration methods have been set out as punctuating the end of an old era and heralding the approach of the new. Perhaps he hoped that he might find exposed an entirely new method of prospecting which would prove to be the touchstone for phenomenal discovery. While no such miracle is yet in sight, the very assembling of all exploration methods, both old and new, in a reinvigorated search for petroleum reserves in new and old territory is an epochal departure from established practice.

For many years the question in petroleum exploration in the Gulf Coast was whether to use the seismograph or the torsion balance. Later the gravimeter took the place of the torsion balance, but other methods were rarely considered. In other areas, such as Oklahoma, when a block of leases was brought up for consideration the first and frequently the last consideration was often whether or not it had been shot. And here and there an oil operator or a geologist still unfamiliar with the principles of some or all kinds of geophysical work viewed them with suspicion and refused entirely to be influenced by them. Rarely were all applicable methods of evaluation carefully weighed and considered.

It is only in the last two or three years that this type of obstacle to effective exploration has disappeared. It is not maintained that all geologists and geophysicists now accept all types of exploration as being effective. But wherever any method is rejected by one of them, the rejection is as a rule the product of his mature judgment based on a knowledge of the scientific principles applicable to the evaluation of the method, and not a manifestation of unfamiliarity with the principles of the art itself, coupled with a remembrance of past disappointments due to misapplication of the method or unforeseen factors which had produced unfortunate results.

EFFECTIVENESS OF EXPLORATION METHODS

By W. R. Ransome
Geophysical Service, Inc.

MUCH talk is always afoot about the present status and future possibilities of geophysical exploration methods. The criterion is usually taken to be the number of units in the field, and future trends in popularity are predicted on the basis of past performance. The effectiveness of a method—its ability to find oil fields—is seldom discussed, even though the amount of oil found depends on the effectiveness of the method even more than on how much it is used.

Of the many methods used the seismograph has been the most used and has discovered the majority of the geophysically located fields. Current opinion has it that seismograph prospecting has shown a sharp decline in popularity in recent months. This is not true. While it is not possible to give exact figures, it is quite reasonable to say that nearly 200 seismograph crews are in use today in the United States, and this number is not far below the peak which was attained in 1937. Furthermore, a good part of the small drop in the use of the seismic method has been compensated by the increase in gravimetric and geochemical prospecting.

The effectiveness of the seismograph, assuming that the major portion of all geophysical exploration work is done with it, can best be judged by the results of wildcat drilling in 1940. Dr. Lahee recently reported that one out of every five wildcats drilled in 1940 on geophysics was a producer. On the other hand, of the wells located without the aid of geology and geophysics, only one out of 24 produced. Such a startling performance definitely shows the efficiency of today's exploration techniques, particularly the seismograph.

However, certain other factors bearing on the exploration record of geophysics must be considered. One of these is the question of whether the ratio of dry holes to producers is being reduced by present-day geophysical prospecting. The record of the past three years shows that it has reached at least a static position, and may even be starting in the other direction. A second, and perhaps more important consideration, is the economic value of the fields which are being discovered. It seems quite clear that both their size and value is decreasing, especially in view of the cost of today's deeper wells.

All this leads to the conclusion that present-day geophysical prospecting, while it is as necessary as always and more efficient than ever before, is declining in economic effectiveness. It is the task of the exploration geophysicist to raise that effectiveness either by discovering new techniques or by applying the old techniques in new ways. It is not the first time that the petroleum industry has asked the question of how to find a more effective way to search for oil; surface geology, the anticlinal theory, fan shooting, and the reflection seismograph itself are earlier answers.

This time, fortunately, the geophysicist is at no loss for an answer; two new problems come immediately to mind. One is the location of stratigraphic traps, and the other is the mapping of structures that have remained undiscovered because of their low relief or their complexity. The first is a new technique; the second is a new way to apply an old technique. Solutions for both problems are now available, and are just now beginning to be generally applied. The latter problem, that of finding low-relief structures, demands the best work that the present-day seismograph can do. First of all, more than the usual care must be taken to get accurate readings of the time-breaks and reflections. A slight error in arrival time, a wrongly figured weathering, or merely a poor record in a critical place, may mislead the prospector into ignoring a small but nevertheless extremely profitable oil deposit. Second, shot points must be put closer together than usual. In the past year or two, many a producing field has been found which was passed by in earlier surveys because the shot points were a mile or so apart, and the evidence of single shot points was discarded. Finally, deep structures, now major oil fields, were missed because reflections were not computed to a great enough depth or were too complex in pattern to be properly interpreted.

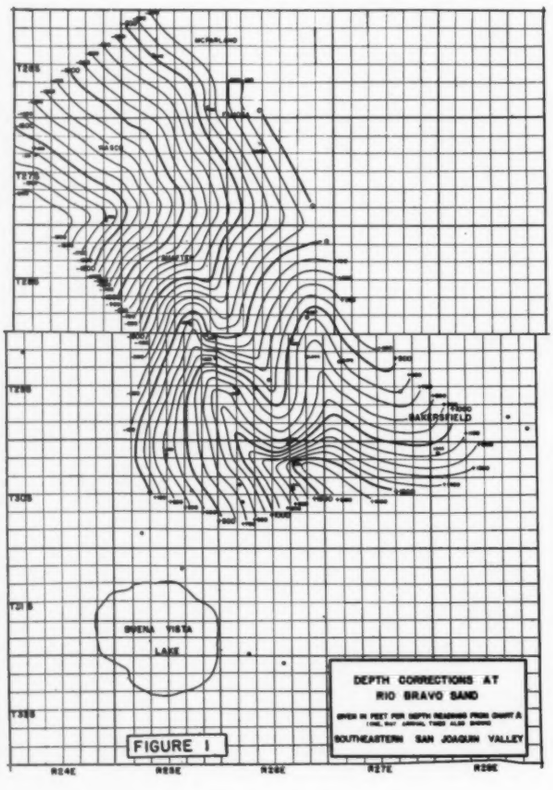
However, even after all the above precautions are taken, it is still not certain that low-relief or complex structures can be found. Seismograph maps that did not conform with the known structural features were observed again and again, and none of the usual refinements would account for the differences. Eventually, though, the velocities which were used to compute the depths were investigated, in the hope that they would furnish a key to the difficulty. It was at once observed that the velocities changed in a horizontal direction to such an extent that they would not only completely hide small structures, but would mask and disguise large ones as well. The trouble was found.

Figure 1 is presented to show the effect of lateral changes in velocity, and to illustrate the need for velocity control. The contours represent the errors in the computed depths of a certain reflecting bed. The depths are computed in a way which gives the correct answer in the middle of the area but takes no account of sidewise velocity changes. Velocity control for figuring out these errors is furnished by wells, whose locations are shown on the map as small circles. Examination of the contours shows an over-all error in depth of over 3500 ft. with local variations as great as 200 ft. in a mile. This variation is quite large enough to hide a good-sized structure.

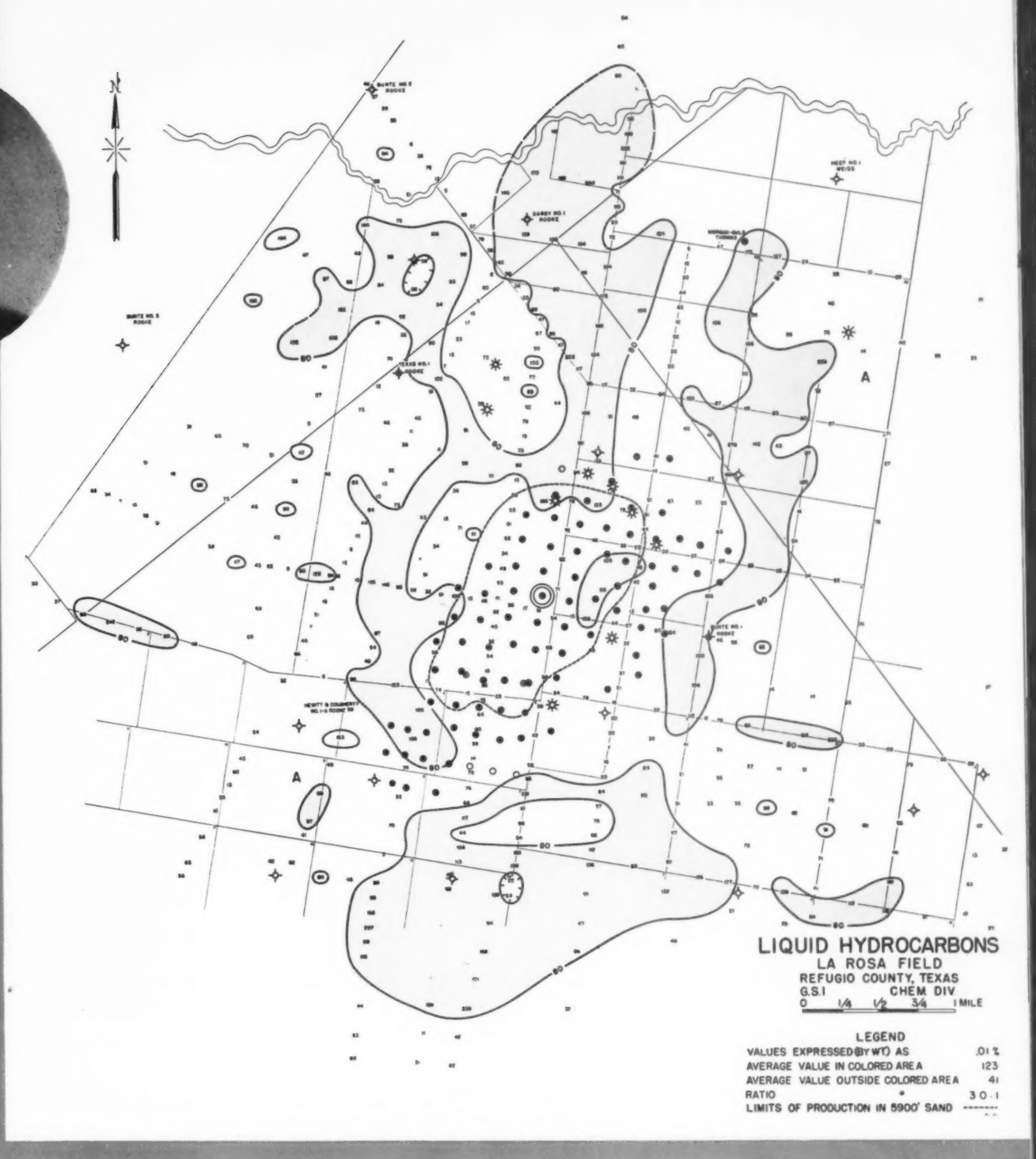
As soon as the effect of sidewise velocity changes is recognized, a technique can be formulated for applying the velocity changes observed from well-velocity control. Furthermore, it is also possible in many areas to determine the velocities and velocity changes as part of routine prospecting, with sufficient accuracy to measure the effect and correct for it. This procedure has been successfully applied in more than one instance, and in certain areas is a recognized necessity for seismograph work.

Another way to increase the economic effectiveness of exploration is to search for stratigraphic traps with geochemistry. This is the new technique mentioned in a previous paragraph. Several successes with this direct method of locating stratigraphic traps have been reported in the literature.

Figure 1: Depth correction map for velocity changes affecting seismograph calculations.



W. R. Ransome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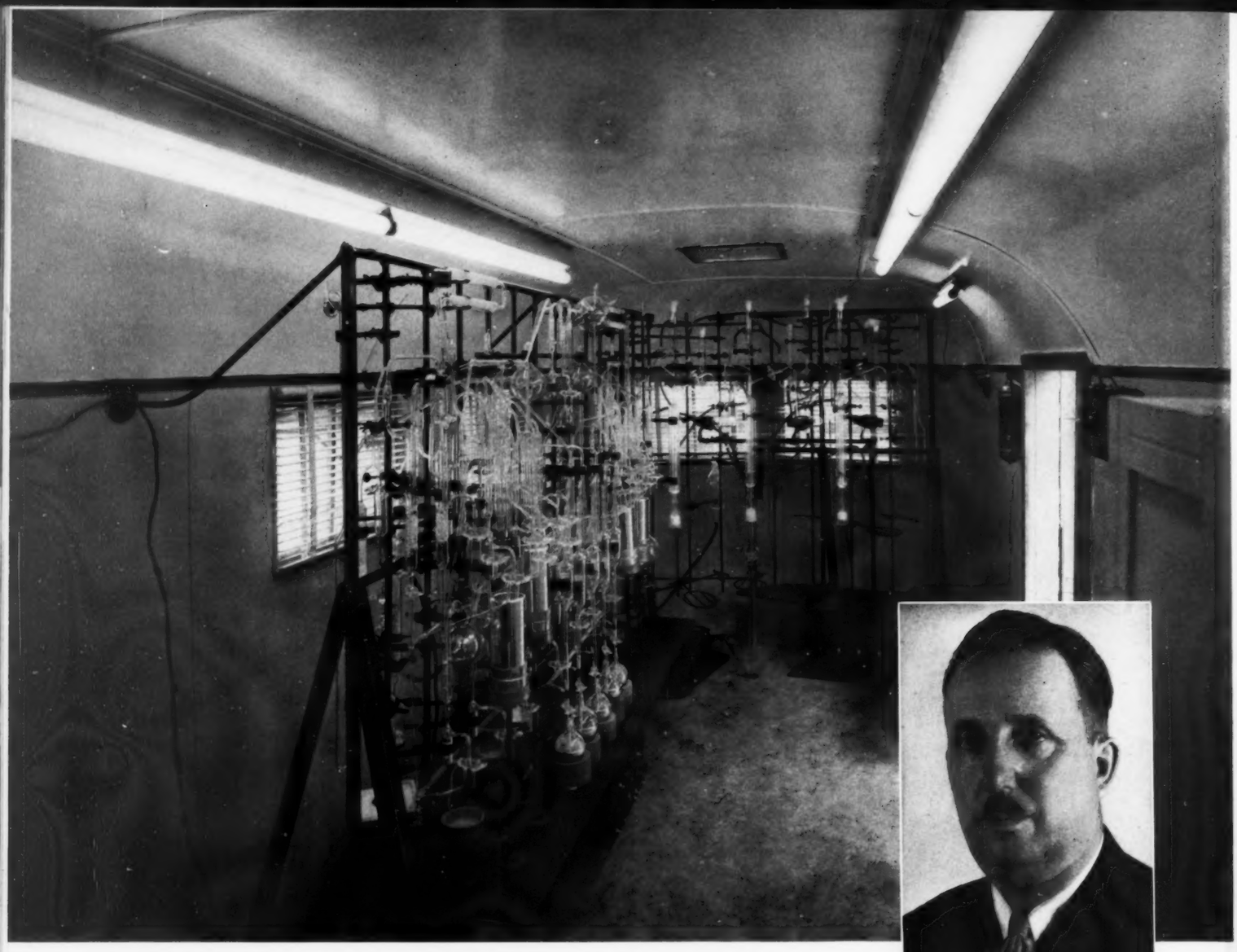
LIMITS OF PRODUCTION IN 5900' SAND

Figure 2: Geochemical survey of LaRosa field and development to date.

In the early experimental work several areas were surveyed with geochemistry where wells were being drilled on seismograph structures. The thought here was to find out if the method would indicate in advance of drilling whether the structure was productive or dry. This was accomplished satisfactorily, but, in the later development work it was found that the field exceeded the productive limits delineated by the seismograph closure. The explanation of this is the presence on the flanks of the structure of sand bodies which pinch out-dip against the structure and are absent over the top. These are usually spoken of as stratigraphic traps.

Figure 2 shows an illustration of this. The field was located by the reflection seismograph and is a true structural trap with at least one blanket sand producing over the fold. The geochemical survey was completed just before the discovery well, indicated by a double circle, was brought in. The producing limits of the principal sand are shown by the dotted line, and most of the 41 wells outside the line are producing from lenses of other sands. These are stratigraphic traps.

Geochemistry's ability to locate stratigraphic traps at a reasonable cost may bring about a renascence of exploration. But whatever the future of the petroleum industry may be, we have at hand methods of maintaining the effectiveness of our exploration at a high level with the consequent assurance of adequate reserves.



Interior view of portable laboratory adapted to both surface and well sample analyses.

John W. Merritt.

Direct Evidence Required to Discover Stratigraphic Traps

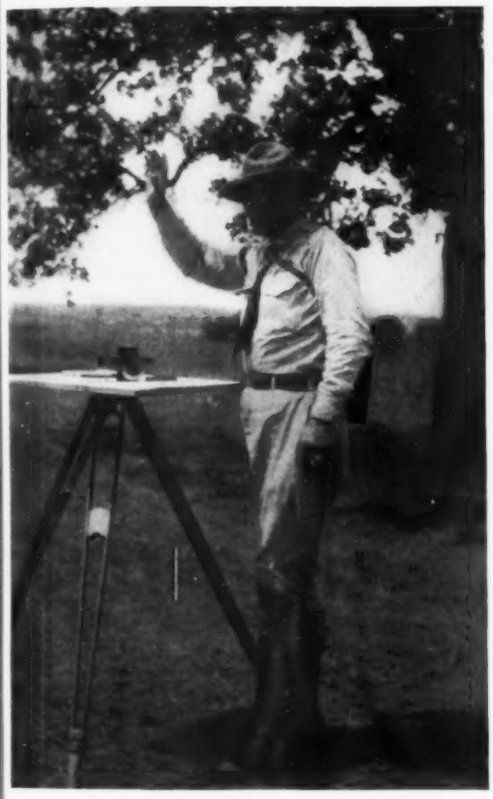
By Dr. John W. Merritt
Geochemical Service Corporation

FROM the beginning of man's interest in the use of the minerals of the earth, the search for these minerals, or prospecting has been carried on by the tracing method. Where loose pieces of ore or float are found, the prospector reasons that they must move downhill or downstream from their original home. He, therefore, works upstream or uphill from his first discovery, seeking other pieces of ore. When the trail stops, the prospector starts digging around in likely places to uncover the ore body. In other words, this method is direct, and is based upon finding of traces of the actual mineral which is sought.

In the early days of oil prospecting the same direct method was employed. Wherever evidences of oil or gas could be found, they were traced to the point from which they actually issued from the ground and the drill was put to work nearby. If enough drilling was done, the prospector was usually rewarded by the discovery of oil or gas production.

Early in the history of oil, however, it became evident that for every oil or gas pool from which actual visible traces of oil or gas escaped, there were several just as good or better pools that offered no such clues of their presence or location. Geologists then set to work and developed the anticlinal theory of oil and gas accumulation, based upon the observation that most oil and gas pools occurred in porous formations accompanied by salt water and, therefore, the oil or gas would accumulate in up-arched traps in which the oil or gas and water could separate from one another and the oil or gas could be kept from moving laterally. With the development of this theory oil activity became really intense and rich rewards were obtained by the intrepid operator using this geological method of exploration. In the earlier days the operator employed the geologist to map all crustal folds or uplifts that could be found by observing the dip of the rock strata exposed at the earth's surface. After a few years of this, how-

ever, the largest and most easily found surface structures were discovered and tested and the rate of discovery began to slow down. About this time it was found that information from underground work, such as drilling of wells blindly and comparing elevations on subterranean strata in adjacent drill holes or even in water wells, often yielded evidences of unexposed structures. This discovery led to planned drilling for structure, usually with the use of core drills. A revival of oil exploration by the use of this method followed with favorable results until areas in which such work could be done by shallow holes were worked over, and deeper and deeper drilling had to be done. The added expense of such deep drilling led to the use of other methods of search for structure which might be less costly. This brought in several geophysical methods, such as the seismograph method of mapping the position and amount of uplift of structure by timing sound waves from surface explosions down to heavy strata deeply buried and back to the surface, and transforming time data into depth data on the basis of observed rates of speed of sound waves in the local formations. Another method of finding the location of deeply buried structures is based upon a delicate measurement of the attraction of gravity. In this method it was found that such structures caused a deflection of the direction of gravitational pull from the vertical so that a carefully detailed map of such observations would lead to the discovery of a structure. A third method of search for structure was based upon the observations that the earth's magnetic field was often disturbed over and around structures. All three of these geophysical methods have been used with success by oil operators, and wherever the work was done accurately, the drill usually disclosed the presence of a subterranean structure. Not all structures, however, contain oil or gas. In fact, far less than half of the true structures discovered in oil producing regions have yielded oil or gas in paying quantities.

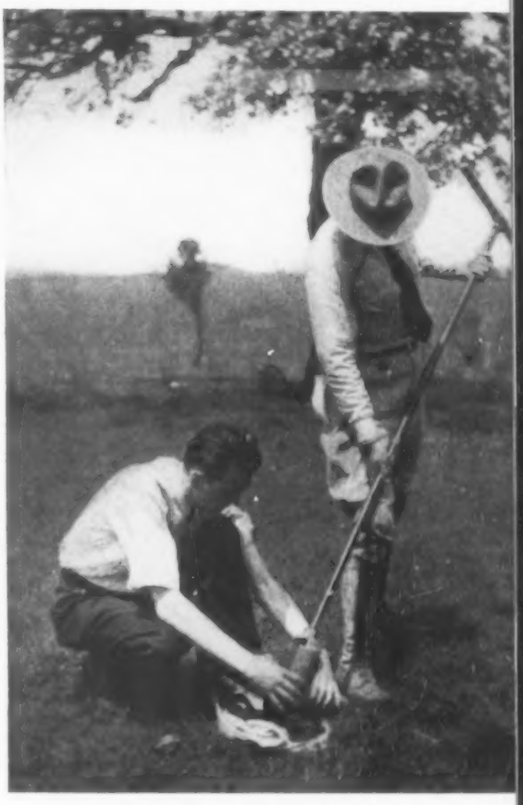


Locating soil analysis test points by plane table method.

It has been long known that not all oil and gas is trapped in a dome or folded structure or against a fault and that in such cases the geologist cannot find the local trap. Such non-structural traps are formed by the deposition of porous sediments, such as ancient shore line strands or beaches or off-shore bars during the deposition of the oil-forming and oil-bearing horizons in ancient geologic times. These porous bodies, when they are tilted, form excellent oil and gas traps and, at the same time yield to the geologist no evidence of their presence other than actual discovery by the drill. An outstanding example of this type of oil deposit is the great East Texas pool. After the discovery and development of the East Texas production the oil operators began to wonder whether this type of production might not in the future become one of the most prolific sources of oil and gas and geologists began the study of regional geologic history in order to learn how to pick localities where such shore line conditions might have existed at the time the petroliferous horizons were being deposited. But even with regional localization of such geological conditions the drill must be resorted to for actual finding of the oil sands and, since such deposits are usually long and narrow, drill exploration must be intensive and, consequently, expensive.

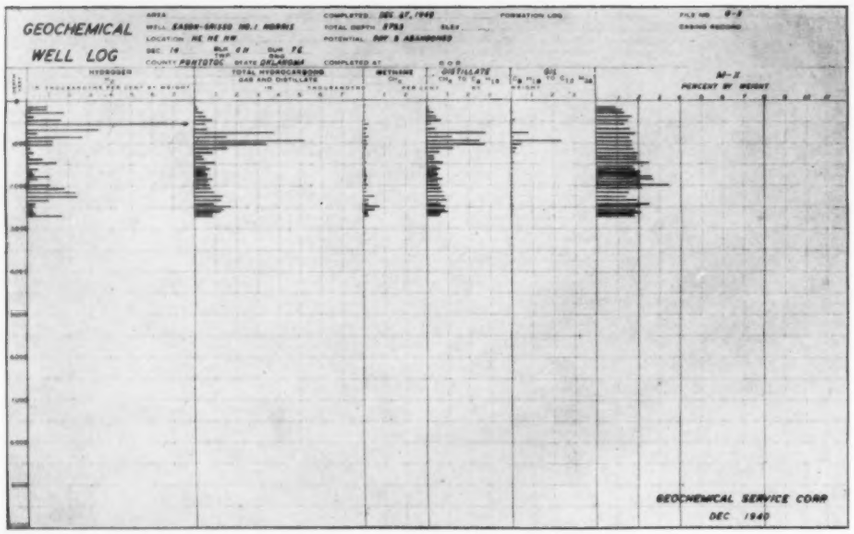
Several years ago, when the rate of discovery of oil and gas by the commonly used indirect methods slowed down because of the decrease in workable territory and the increased costs of such work, scientists reverted again to speculations about the development of a more direct method. It came to mind that no rock is wholly impervious to the passage of such mobile substances as hydrocarbon gases and that, given time and sufficient subterranean pressures, possibly a measurable quantity of such gases might be escaping at all times from deeply buried oil and gas bodies.

Accordingly search was made for traces of such gases above known oil and gas bodies and, sure enough, there they were. These hydrocarbons were found both in the pores of the soil and also adhering to the surface of the soil particles. Analysis over all parts of the producing areas and extending outside them disclosed a characteristic pattern of relative hydrocarbon values, and the halo theory was brought forth. This theory is based upon the observation that most of the time there is a segregation of high hydrocarbon values in the form of a band or ring lying immediately over the edges of the oil or gas body and that this halo is related to the presence and position of the oil body whether there be a structure containing the oil or whether the oil be in a non-structural trap. As this new method of exploration went on and was put to test far and wide there naturally developed many failures, but the failures were made use of to correct faults in laboratory and field technique and this resulted in the continuous improvement in the new method of exploration. And now the oil industry is beginning to return to the direct method of oil exploration from which it departed several decades ago. This by no means implies that the indirect methods are not longer useful, nor is this geochemical method offered as a substitute for the successful geological and geophysical methods, but it is now added to the others as a collaborative and corroborative tool for the use of the oil operator.

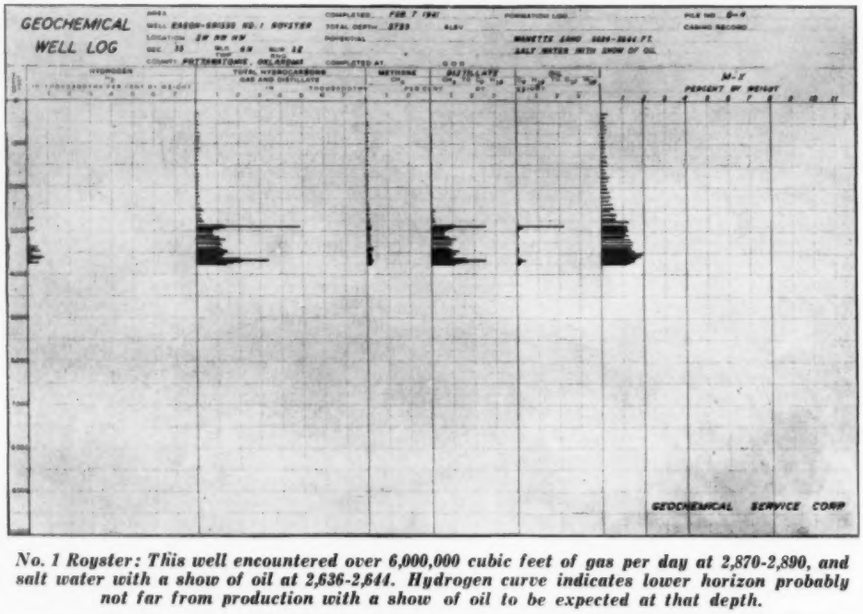


Catching sample on sample cloth and loading sample jar.

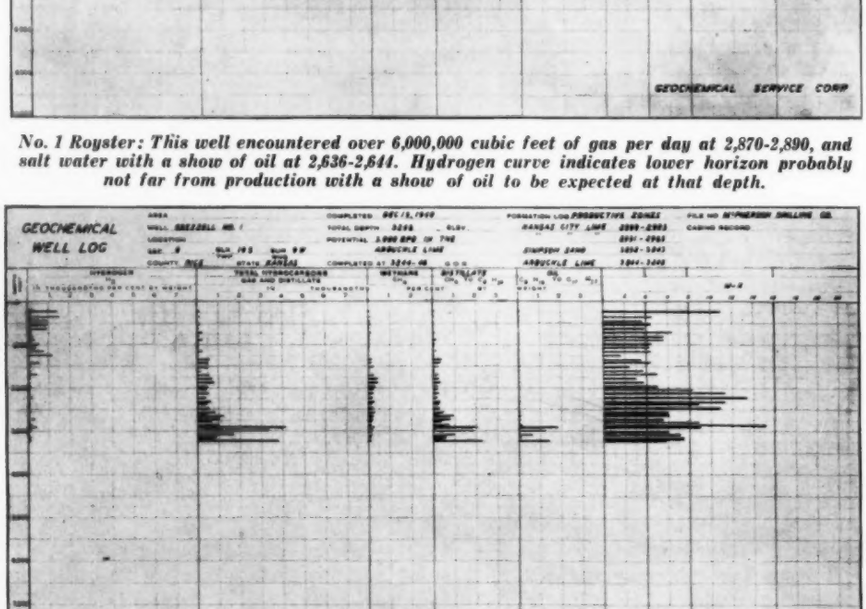
Objections have been raised to the halo theory by stating that accidental high hydrocarbon values can be grouped by the geochemical interpreter to form halo or marginal ring patterns and that it is impossible for hydrocarbons to reach the surface from great depth in measurable quantities. In the beginnings of surface geochemistry, popularly called soil analysis there existed no proof of the upward movement of these substances. Lately, however, petroleum geochemistry has taken in the third dimension in the study of hydrocarbon ac-



No. 1 Norris: Hydrogen and hydrocarbon curves unfavorable. Light shows of oil or gas to be expected between 500 and 1,000 feet. This well was probably not far from a producing area.



No. 1 Royster: This well encountered over 6,000,000 cubic feet of gas per day at 2,870-2,890, and salt water with a show of oil at 2,636-2,644. Hydrogen curve indicates lower horizon probably not far from production with a show of oil to be expected at that depth.



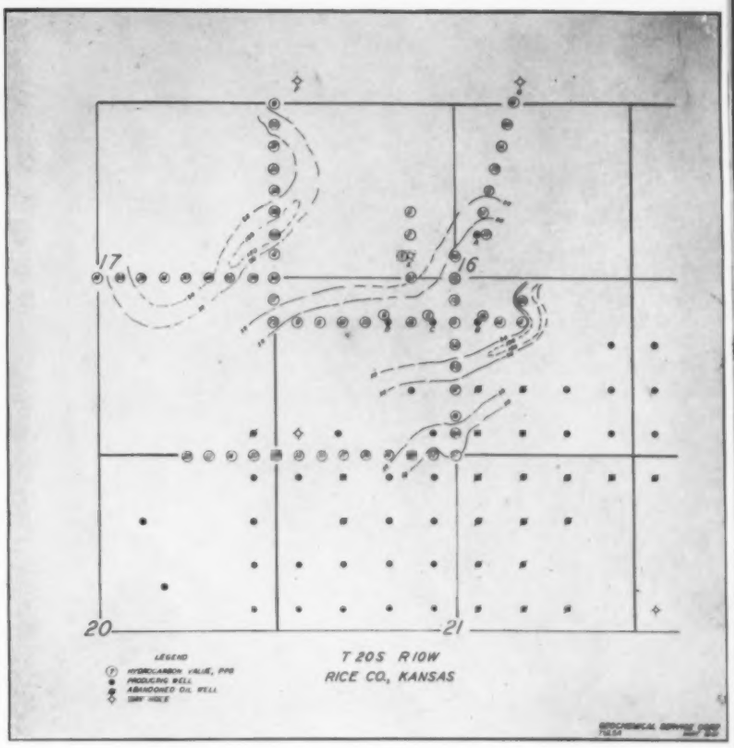
No. 1 Grezzell: Geochemical well log of good producing well. Hydrogen curve indicates location well within producing area. Hydrocarbon curves indicate production in two Kansas City lime zones and in Arbuckle lime.

cumulations found in cuttings from drilling wells with the result that these hydrocarbons are found above production and in increasing values as the well approaches the pay sand. A distinctive tridimensional hydrocarbon pattern has also been found which proves the theories developed earlier in surface studies. Subsurface geochemistry is not useful alone, however, in supporting surface theories; geochemical well logging has also a very useful and valuable practical value. By this means the operator can sense the approach of his drill to a pay horizon often as far as 500 to 1,000 ft. in advance. Likewise the chemical log shows when the pay zone has been passed. The geochemical log can also smell oil laterally from cuttings where saturation at the point drilled is light or absent. Frequently producing limestone horizons are exceedingly variable in the degree of saturation, and it has been possible to drill through such zones without finding any trace or oil in core or cuttings, or any evidence of saturation by other geophysical means. It has been found in some cases that a shot or acidization or both may bring the oil into the hole from some nearby saturated area. Many a well has been drilled, however, and the pay horizon cored and the well abandoned because of the lack of evidence of oil nearby. The geochemical well log, therefore, becomes a life insurance policy against an unnecessary dry hole, where the oil lies below the bottom of or to one side of the drill hole.

The procedure in geochemical surveying is as follows: (1) earth samples are taken in grid or profile patterns at various intervals over the area to be examined, sealed in jars and shipped to the laboratory, with all possible care taken to prevent contamination; (2) analyses of the hydrocarbon constituents of each sample are made; (3) the hydrocarbon values are plotted on a map at the sample points and the pattern of relative values contoured in, after which (4) the interpreter forms his opinion as to the meaning of the results found and makes his report. Much use of this method of exploration is being made in following

Locating soil analysis test points by compass and chain method.

Boring for sample with earth auger.

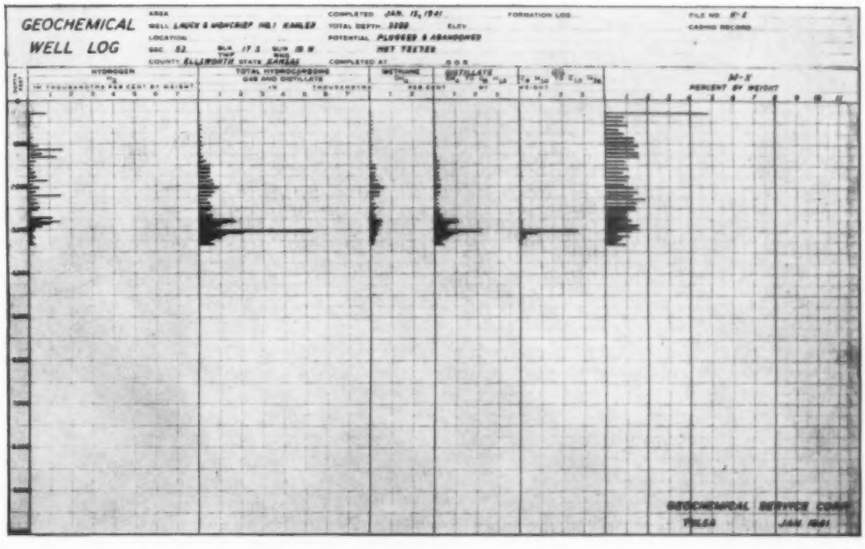


All the wells and dry holes shown in the above illustration excepting those marked 'A,' 'B,' 'C,' 'D,' and 'E,' were drilled before the geochemical survey was made. There are three producing horizons in this field, two in the Kansas City lime zone and one in the Arbuckle lime zone beneath it. The main field produced from Arbuckle lime and the present limits of the Arbuckle lime production have been reached. The object of the survey was to determine how far north the Kansas City lime production might reach beyond the Arbuckle lime production. The southernmost halo band as far as mapped marks the northernmost limits of Arbuckle lime production. The second halo band to the north is interpreted as marking the northernmost limits of one such horizon. The third marginal high value zone was interpreted as marking the northernmost limits of all Kansas City production. Following the report Wells 'A,' 'B', and 'C', were drilled by the client, and Well 'E', was drilled by another operator. The fourth or northern-most marginal anomaly zone probably marks the eastern or southeastern limits of a third partially developed oil pool which lies west and northwest of the fourth anomaly band. Well 'F', and 'G' carried shows of oil indicating that well 'F' is probably just outside of production lying to the west or north. A continuation of the line of samples through Well 'G' should also find an anomaly point which might connect with the third or with the fourth anomaly band.

out the oil or gas from a partly developed field to its ultimate limits with the resultant elimination of unnecessary dry holes.

The hydrocarbon pattern developed by contouring the values after a surface geochemical survey may be in the form of a simple closed belt of high values surrounding the favorable area, or it may be very complex. Irregularities in pattern develop from such causes as spotty saturation or numerous pay sands at different horizons. Where the problem is that of extending production out from a partially developed pool (always a dangerous thing to do with the drill), the interpreter looks for his halo band to come in beyond the limits of production and keeps his client from spending money except between the halo band and production.

In geochemical well logging cuttings are shipped daily to the laboratory from the well and analyzed for various hydrocarbon constituents and sometimes for inorganic mineral constituents and the results plotted on a progressive graph. As information accumulates progress reports are made to the operator as a guide to his drilling procedure. Advance information which enables the driller to know ahead of time whether a formation which the drill is approaching carries oil or gas or is barren is exceedingly useful in the matter of deciding how to drill and whether to test the horizon. Frequently this information enables him to save considerable unnecessary expense in coring, setting pipe or testing. When the hole is finally completed to contract depth, if no production has been found, it sometimes happens that



No. 1 Kahler: Hydrogen curve indicates well to be located near the edge of production. Hydrocarbon curves indicate possibility of light producer at about 3,000 feet.

the geochemical well log shows clear indications of oil or gas below. In this case the operator is urged by the geochemist to continue drilling until the pay horizon has been reached and tested. Such advice, if followed successfully, results in turning a failure into a producer. Frequently the completed well log shows the presence of oil and gas above the bottom of the hole at a point where a core or cuttings indicated no oil. In this case the operator is advised to test this horizon by the customary means, and again the advice may result in turning a dry hole into a producer.

Taking them together, geochemical surface surveys and geochemical subsurface examinations tend to save unnecessary drilling and also to save unnecessary dry holes. These things would not be possible except by a direct method of exploration. Their use results in economies in a costly division of the industry's activities.

Water Prospecting with the GRAVITY-METER

By E. V. McCollum
Mott-Smith Corporation

Several New Techniques for Gravity Meter Prospecting in Swamps and Deeper Waters to Fifty Feet.

DURING the past several years geophysical methods have made rapid strides in adapting themselves to the prospection of areas covered by water. Such areas may consist of swamps, shallow or deep lakes, protected bays, or the ocean itself.

The gravity-meter is admirably suited to water work where reconnaisance data is desired, since good coverage at relatively low cost is possible. The gravity-meter being light in weight may also be taken into areas that present considerable difficulties to methods requiring heavier equipment.

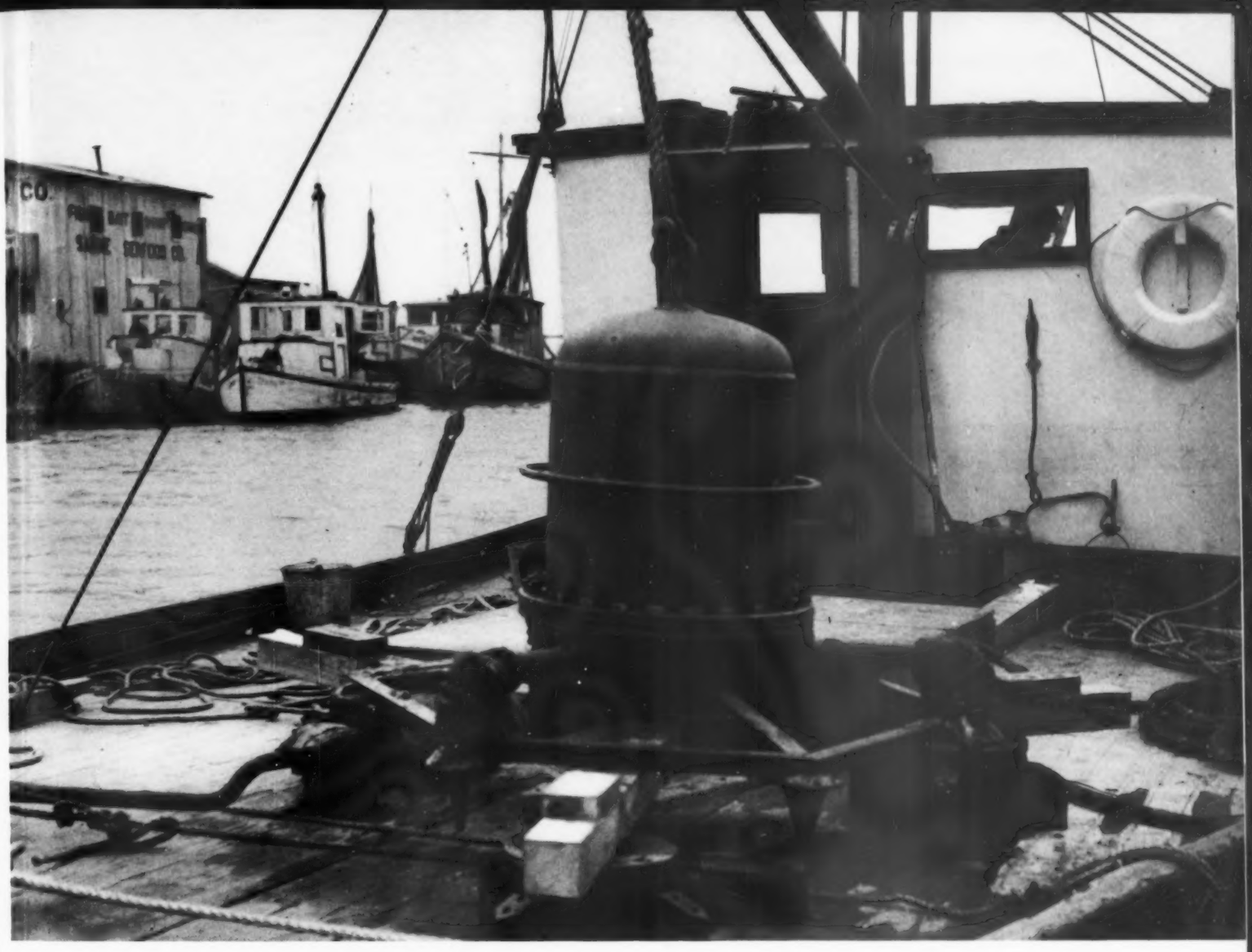
One common method of using the gravity-meter in areas such as swamps and marshes that are partially water covered is to transport the instrument by boat. Readings are obtained by setting the instrument on improvised piers constructed on the spot, tree stumps, etc. Boats of very shallow draft may be used where only a few inches of water is present. A boat commonly used for this purpose utilizes an aeroplane propeller means of locomotion; the speed thus obtained permits a goodly number of stations to be obtained during a day's work.

In shallow lakes it has sometimes been found convenient to place a well in the bottom of the boat; tripod legs are then lowered through this well and observations taken in the same manner that is common practice on land.

In lakes or bays where the water ranges up to 20 or 25 ft. in depth considerable areas have been worked by using portable towers or piers. Such towers have a platform sufficiently large to accommodate a gravity-meter and its observer. Trustworthy readings may be obtained by this method in the presence of waves ranging up to some three feet in amplitude.

The latest mode of using the gravity-meter in water covered areas is to place the instrument in a submersible chamber that is designed to withstand water pressures ranging up to several hundred feet in depth. The instrument manufactured and used by the Mott-Smith Corporation is leveled and read electrically on a control panel located in the cabin of the boat in which the meter is transported. The underwater gravity-meter weighs approximately 350 lbs. and is handled by a power winch and boom which lifts the instrument over the side of the boat. An ob-

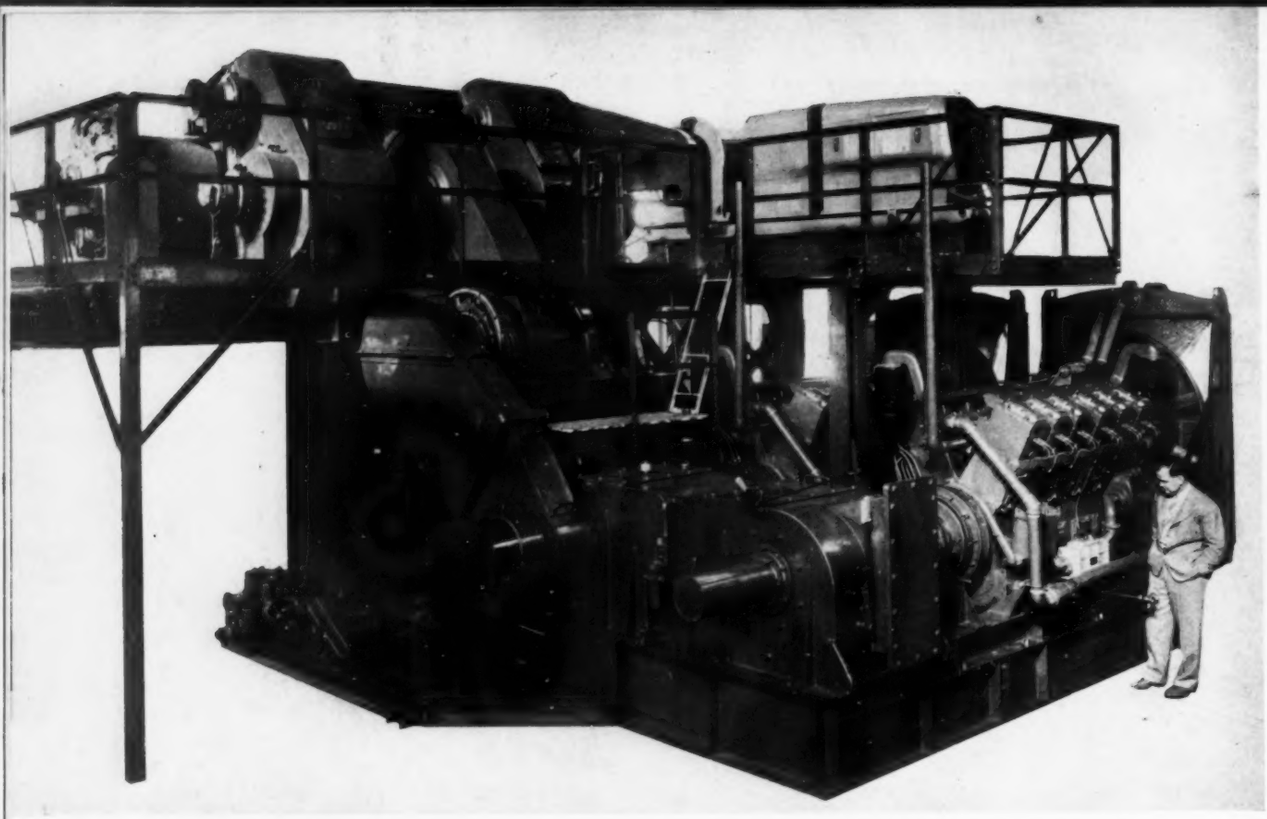
Boat with portable tower off the coast of Cuba.



Above, underwater gravity meter in dome on deck of boat; Right, shallow draft boat used to transport gravity meter which is shown being lowered into the water.

servation requires only a few minutes under favorable working conditions. Obviously the speed of a survey is largely dependent on the weather and the speed of the boat being used, but an output of 25 stations or more per day may at times be attained.

The underwater gravity-meter proves quite useful in extending the control on structural features that are located in part in areas accessible by land. The instrument in its present form may be used to obtain control well beyond present drilling depths. No serious obstacles are foreseen in increasing the working depth considerably if and when the need arises.



Fred C. Ripley Jr., the author, inspecting one of the most complete custom built rigs ever produced: two large engines approximating 900 hp. were designed to drive only the drawworks and table but may be compounded to drive the pumps if necessary.

INTERNAL COMBUSTION

Drilling Rigs to Fit The Job

By F. C. Ripley Jr.
Manager Export Sales
Emsco Derrick & Equipment Co.

COMPARED to his predecessors of a few years ago, the present day drilling equipment purchaser finds himself in an enviable position. A contractor or operator needs only to think he is in the market for an internal combustion drilling rig and the psychics of the supply world will be beating at his door with offerings to fill his every need. Being an astute buyer, he will have in mind a set of conditions which are governed by the work projected. He may desire to adapt the equipment he has on hand to suit his needs, or he may settle for a brand new machine. Possibly he may have a set of hard and fast conditions for drilling upon which to establish the purchases, or he may desire a rig to perform a number of drilling jobs varying in depth and in speed requirements. Still again he may be a foreign operator with the serious problem of transporting, even to flying, the rig to an inaccessible location.

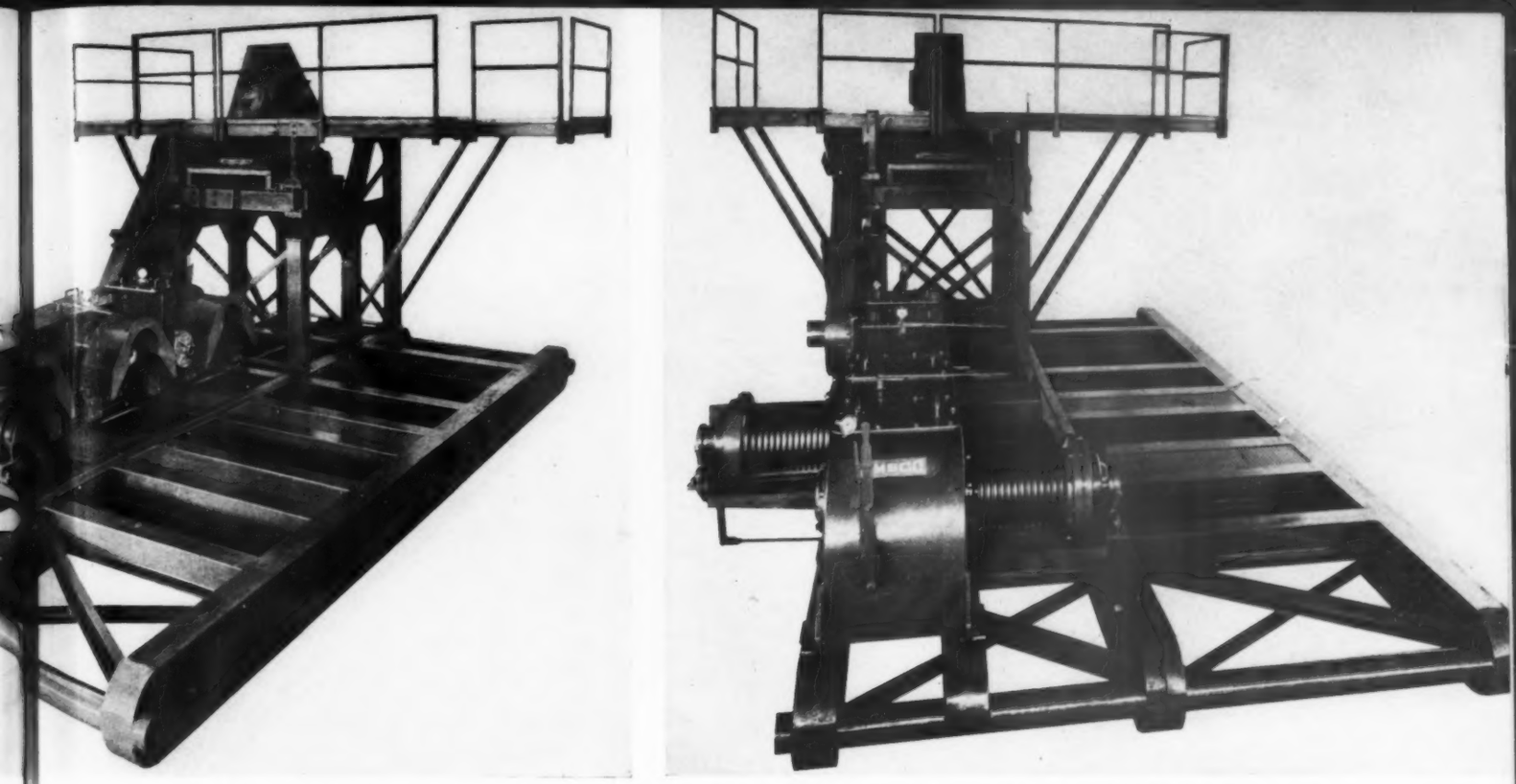
Generally speaking, there are three classes of internal combustion drilling machines on the market today. These machines in each class are constructed for the lightest to the heaviest work. For convenience, let us say that these classes of equipment are as follows: one, the converted steam rig; two, the custom built machine; and three, the unit type power rig. The converted and custom built rigs are quite similar in construction and could probably he considered as being of one class. These machines are without a doubt the most versatile now on the market as far as meeting construction demands by the customer is concerned.

The custom built or the adaptation from steam rigs has many characteristics in common with the older type of equipment. Vast improvements, however, have been made in both the design and operation of the machine, and the present models are therefore thoroughly up-to-date for the purpose they are intended to fulfill.

Fundamentally, the machines consists of a standard multiple jaw or friction clutch drawworks which is usually equipped with double clutch sprockets on the jackshaft which raises it from the regular three or four speed to six or eight speed. Behind this drawworks is a master forward friction clutch and reverse gear driven from a totally enclosed flood lubricated compound transmission case. Coupled into this case are two or three engines of any aggregate horsepower limited only by the capacity of the forward clutch.

These machines are called custom built because with this design it is possible to meet a number of requirements at the customer's suggestion. The drawworks may be raised to as much as 12 ft. above the ground, while the engines remain at ground, or low substructure level. Any make of engine desired by the customer can be used with an aggregate horsepower and speed compatible with the capacity of the master clutch and compounds. Many operators prefer to use as much of their steam equipment as possible. In this case a regular four speed steam drawworks can be cheaply changed over to six to eight speed, and can be used with the reverse clutch and compound transmission with complete satisfaction.

Most designs of custom built machines are of such a conservative nature that there is a possibility of applying additional power to the hoist by the addition of another engine, or larger engines. This practice is not necessarily condoned by the manufacturer, but it can, with reasonable safety, be done. One manufacturer



Two views of a three-engine, four-shaft, custom built rig before engines or drawworks were installed; note that two pumps may be hydraulically compounded making it possible to control speeds.

has had a 700 hp. two-engine machine raised in horsepower to 1000 by the addition of a third engine. Another instance concerns the addition of a fourth engine to a three engine transmission. In both instances there were no changes made in the master clutch or compounds. Other illustrations could be pointed to where some slight changes have been made when the power was increased. Noteworthy is the fact that the custom built machine lends itself, with reasonable safety, to changes which will enable an operator either to increase the depth capacity of the rig or get himself out of trouble as the case may be.

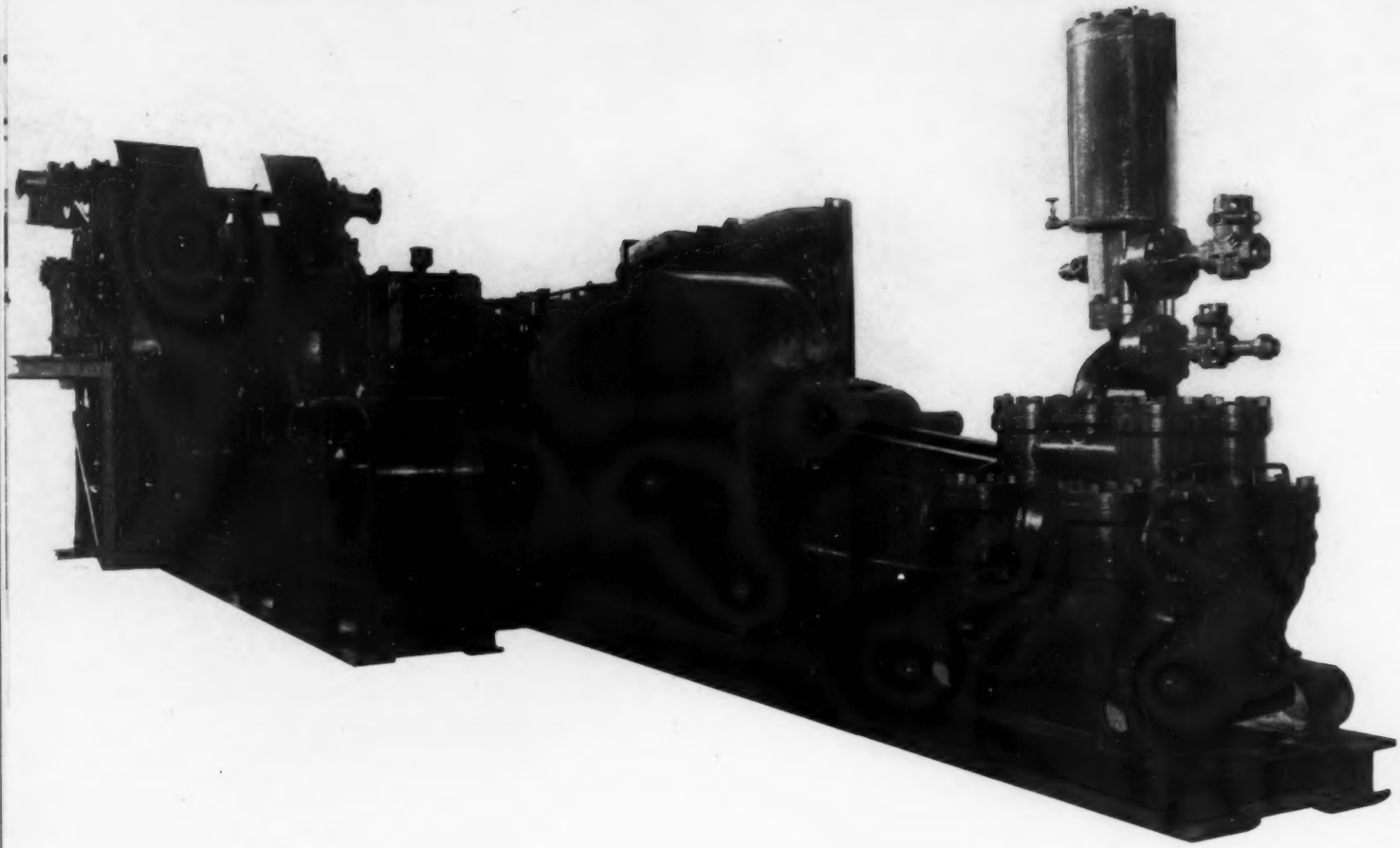
In operation this custom built unit approximates steam in control. The reverse is instantaneous and all of the clutch pedal assemblies are standard as with steam. Generally this type of machine is a trifle slower in operation and control than the rigs on the market known as the unit type power rig. They are, however, extremely simple, and any steam driller can make repairs on the drawworks end the same as he would on a steam rig. A minimum number of friction clutches are used on these rigs based on the theory that the fewer operating parts required the more consistent and economical will be the operation of the rig. Where these friction clutches are used very low contact pressures are used to reduce the danger of clutch breakdowns. Hydraulic boosters and air controls are available for the actuation of the master forward clutch, although they are not generally in use on this type of machine. A 1000 hp. rig is operating in California which is completely manually operated. If clutch pressures were to be increased it would become more difficult to engage the clutch manually, and this would give rise to the use of air and hydraulic controls, which can be a booster system or an actual automatic control. These clutch pressures necessitating the form of automatic control will vary from 30 lbs. up to 100 lbs. psi.

For rule of thumb comparison of horsepower ratios for depths compatible with steam drilling time, it might be said that 275 hp. is sufficient for 3500 ft. of 4½ in. drill pipe; 450 hp. for 4500 ft. to 6000 ft.; 600 hp. for 6000 to 7500 ft.; 800 hp. for 7500 to 8500 ft.; 1000 hp. for 8500 to 10,500 ft.

It should be noted that the above enumerated list be considered as a point of horsepower saturation for the specified depths. In other words, with additional horsepower for the same depth the crews would find the excessive speed too difficult to handle and some power would be left without employment. A steam rig for a depth of 10,000 ft. using 350 lbs. of steam and 14 in. by 14 in. engines will have about 1800 to 2000 hp. available at the drawworks, whereas a mechanical rig with 1000 hp. would drill just as fast. Additional power has been proven to be excessive, and constitutes more of a reserve than a usable power. Drilling times in deep areas show this to be true.

Competitive to the custom built machine is the unit type power rig which has been referred to previously in this article as the third type of machine available. This type is very well known to the industry for its compactness, ease in control, and speed of operation. So far as is known there are no figures to prove that the self-contained rig is faster in overall drilling time than an equally powered custom built rig, although the ease of operation, at least up to the point of the crew's ability to handle pipe, might lead one to believe this is so.

These unit type power rigs are noted for the fact that most of them are built for mass production, and give the operator the most for his money, initially, within limits of horsepower input. Generally the rigs cannot be changed in design except for the raising of the hoist position a limited distance above the power end. Many of the units are built for one particular engine, although most have a possibility of a limited selection. Unfortunately, this selection, particularly in closely integrated warehouse practices such as in export, might not allow for a standardization on a particular make of engine through the field operations. In the United States this is more or less secondary to having a good rig. However, it is a problem in overseas operations. The unit type of power rig finds its maximum usefulness in exploitation drilling or in areas where known depths are to be reached. This is for the reason that with a specified amount of horsepower these rigs perform superbly and with utmost speed. The unit type of power rig can be had with a variety of automatic control details. This variety expresses the desires of various manufacturers to create what is considered to be the ultimate in handiness, particularly as applied to control and transportation. However, there



Custom built power rig, manufactured by Emsco: designed to drill to 7500 ft. and yet permit transportation by road where laws restrict the width, with the minimum amount of dismantling.

is a very real danger that some of these rigs may become overly complicated.

In construction they usually have numerous uses of friction clutches which are placed at most strategic points for ease in handling. Some manufacturers employ low clutch pressures and handle them either manually with a booster or fully automatically. The higher the clutch pressure, the heavier the clutch must be and the more complicated becomes the installation.

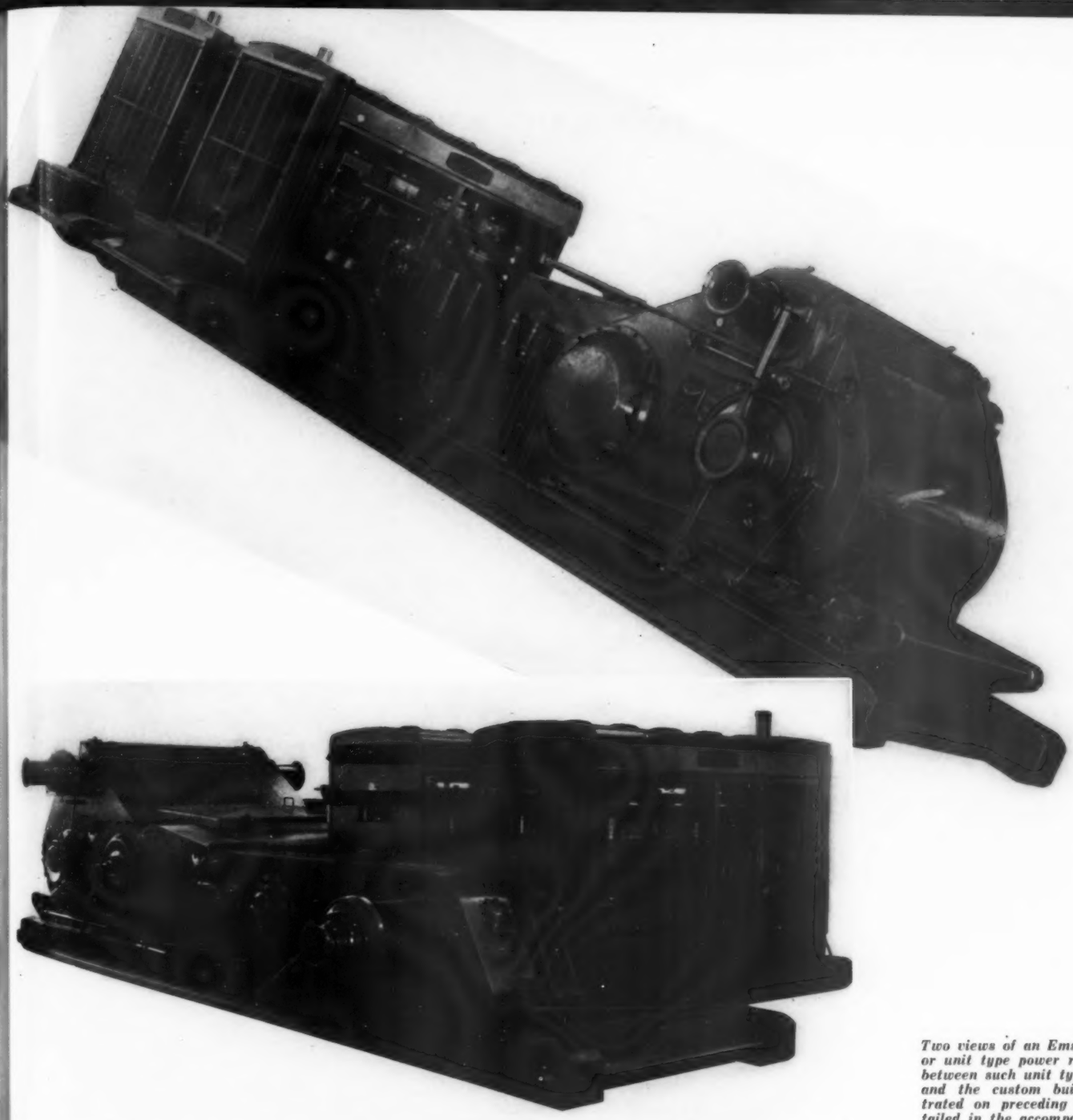
Of comparatively recent development has been the use of friction clutches on the drum shaft. Various manufacturers now use friction clutches on both the high and low, although most prevalent is the friction clutch on the high and the jaw clutch on the low. This seems compatible with conservative practice. Here again various clutch pressures are employed running from 30 lbs. psi on the clutch face to as high as 90 lbs. psi. Again, as the pressures go up, the actuation of these clutches depends to some extent upon assistance to engage them. This likewise tends toward artificial cooling with either forced air or water circulation. It might be noted here that an old axiom states that a drum clutch should be able to do the same amount of work as the drum brakes. Therefore, if the clutch is smaller in contact surfaces than the brakes, the clutch is called upon to do equivalently greater work.

In speaking of drum shaft clutches, it might be noted that at present there are two large steam machines equipped with friction drum clutches on the high side. The performance and ease in operation of these friction drum clutches even when steam driven has been recognized. These two models of drawworks are the biggest on the market today, and are capable of drilling to depths in excess of 15,000 ft.

The unitary rigs are available in all sizes up to 1000 hp. An interesting point in the comparison of custom built and unit power rigs is that the custom built units weigh roughly twice as much per horsepower as do the unit power machines. The weight in the custom built rig is primarily due to the designer's using the stress analysis customary with steam rigs. The variety of designs in which they are available takes them out of the stock class of equipment and gives the manufacturer more latitude in construction. On the other hand, the unit power rigs give the operator as much for his money as it is possible to do within a given price. This type of rig is designed primarily for standardization of parts, for economy in building, for light weight, and for elements of ease of control all of which are not found in the custom built machine.

As for fuels, the present internal combustion types of equipment, depending upon the operator's selection, are capable of taking Diesel, gas, butane, or gasoline power. It might be said that for overseas the use is 100 percent Diesel, although some gas-gasoline machines have been sold for this service. In the Mid-Continent area of the United States, Diesel was first used almost exclusively, but for later years this type of power has given place to gas-gasoline, burning either butane, natural gas, or in some instances gasoline. California never indulged in Diesel to any extent, starting off on natural gas or gasoline and more recently using butane. Fuel for these rigs is based almost entirely on its availability and cost. Price per 1000 mcf. will run anywhere from two cents to 20 cents in value, and thus it can be seen that fuel is a major expense, particularly where a rig is being used for wildcat purposes.

A question that currently arises involving an internal combustion machine concerns the econ-



Two views of an Emsco power rig, or unit type power rig: difference between such unit type power rigs and the custom built rigs illustrated on preceding pages is detailed in the accompanying article.

omy in operation, the chances of breakdown, and loss of time for replacements. Available figures show that when considering an internal combustion machine as a whole as against a complete steam rig that consumable materials, including bona fide engine parts, lubricating oils and greases, are just about the same for either rig. Capital overhauls at periodic times will show steam to be considerably more expensive. These figures are based upon the necessary care to boilers, fuel and water pumps, together with the steam ends of the pumps and hoist engine. The experience herein quoted is based only upon the custom built rig and not upon the unit type of rig. It is questionable that the same result will be gained from both rigs due to the fact that the unit type rig has more operating parts than the former, is not built as heavy and strong, and therefore will cause more trouble and will not last as long.

The element of personnel in costs depends largely upon the operator's location and the availability of a part-time mechanic. Many power rigs are operated on the principle that periodic overhauls are sufficient care allowing the driller to take care of lubricating and incidental adjustments. A steam rig on the other hand must have three shifts of firemen on the rig all the time. A garage mechanic in an organized field can take care of any internal combustion engine for long periods of time along with the other garage work. As for drillers, the custom built machines may be operated by a steam driller without any coaching whatever. Some stock rigs with steam-like controls likewise do not require coaching of the personnel. Those machines with air controls have features in them which are entirely different from any steam application, and it is thus necessary to get a driller familiar with the rig.

In conclusion let it again be stated that, to present common drilling depths, there is an internal combustion machine available to suit the particular characteristics of any operator. He can have a relatively cheap product using his own equipment as much as possible. He may have equipment built to last the lifetime of an ordinary steam rig or he may buy the type which performs with extraordinary precision, is lighter and gives excellent service for a prescribed program.

BARGE MOUNTED DIESEL ELECTRIC RIGS

By A. H. Rowan
Rowan Drilling Co.

&

H. E. Dralle
Westinghouse Electric & Manufacturing Co.

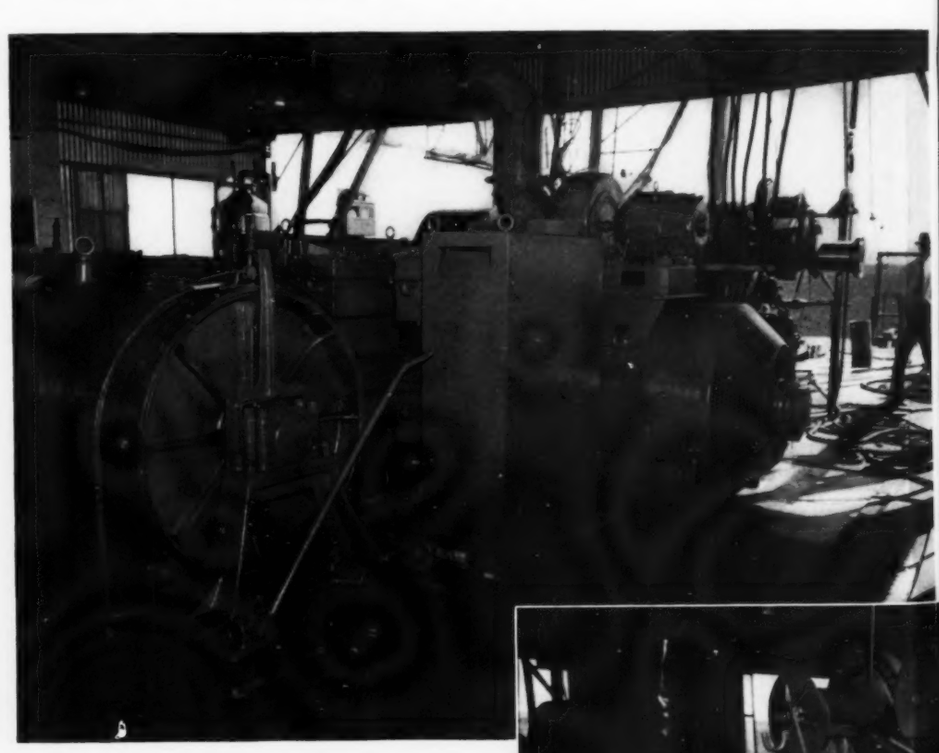
As most commonly used, a variable voltage equipment comprises several direct current generators of medium capacity, up to 250 kw, for direct connection or belting to gas or Diesel engines, complete with voltage-varying control for supplying power to the operating motors driving the drawworks, table and mud pumps on a rotary drilling rig. This form of drive has been time-tested and proven in rotary drilling as one of the most reliable, flexible, and economical in providing a smooth, even, flow of power to the operating equipment. To obtain these features, there are two methods of operating the generators; series and parallel. These will be discussed in order to show the relative performance characteristics of the two types.

The earliest drives employed only two generators for series operation—one for furnishing power to the table through the drawworks and one for supplying power to the mud pump during drilling operations. In hoisting, the two generators were placed in series to supply their full current rating at double voltage to the hoist or drawworks motor. This series arrangement of generators because of its flexibility is a very desirable one particularly for drilling wells of moderate depth where 2-200 kw generators may be used to supply 400 hp for hoisting and 200 hp for the mud pumps.

In this system, if the generators are rated at 200 volts, the mud pump motors will also be rated at 200 volts and will, therefore, operate at full rating and speed at this voltage. During drilling, the drawworks motor also would operate on 200 volts at full torque but at half speed. When hoisting the two generators are placed in series to deliver the same motor current and the same motor torque as at 200 volts, but obviously the terminal voltage of the motor becomes 400 volts, causing it to run at double speed and hence to deliver double horsepower, thereby minimizing the time for coming out of or going into the hole. The speed-torque characteristics of a motor taking power from one generator or from two generators in this series connection are shown by curves "A" and "B" respectively in Figure 1. (Page 84)

With this series arrangement, it is apparent that even with a single generator, full torque is available on the drawworks motor, a fact which would permit performing any desired function on the drilling well but necessarily at reduced speeds as shown on the curve. This is evident from the fact that torque on the motor is a function of its current. Since the generators are in series the motor current, and hence the torque, is the same regardless of whether only one or two generators are in use, but with one generator the speed of operation is one-half that with two generators. Horsepower, being the product of speed and torque, is doubled therefore on the drawworks motor when the two generators are placed in series because the voltage and speed are doubled.

Within the limits of capacity of this type of equipment, there is no more reliable and flexible form of motive power for drilling. Unusual was the installation shown in the accompanying illustration of Noble Drilling Company's equipment using several generators rated at 100 volts each so that when all are placed in series the terminal voltage at the drawworks motor is within the voltage rating of the motor. Such an arrangement is extremely flexible, because loss of a single generator merely reduces the motor operating speed in proportion to the resultant reduction in terminal voltage. Also the generator ratings are such that it permits the use of high speed, industrial type engines of either gas or oil type, carrying a relatively lower cost and much lighter unit weight. And weight is an important item when considering mobility of apparatus. While this particular and unusual unit as shown has a very enviable and noteworthy record in deep well drilling, due principally to the skill of the electrical operator, it is not one to be generally recommended over the ones employing fewer machines of larger rating.



Variable voltage equipment viewed from rear of drawworks showing generator field resistor racks with four oil-immersed master controllers operable from derrick floor.

The parallel system of operation of generators has been the direct result of deeper and deeper drilling which in turn has required larger and larger horsepower for both mud pumps and drawworks. Since both drilling and mud pump motors are of such capacity as to require the output of more than a single generator for maximum output, the parallel system better fulfills the requirements of flexibility without reducing the reliability.

In parallel operation the terminal voltage of the generators is always the same as the rated voltage of the motors, usually 400 volts to minimize sizes of wiring and control and still keep within reasonable safety limits for the operators. Referring again to Figure 1, it is evident from curves C and A that with a single generator, on the parallel system the motor at no load will operate at double the speed that it would on a series system. With two paralleled generators or two seriesed generators the performance characteristics of the operating motor are exactly the same, as shown by curve B.

To clarify the often conflicting ideas regarding the relative performance of motors with the two systems we shall follow through a specific example.

With one series generator (See curve A) the 400 volt operating motor will move any load requiring a torque of 5500 lb. ft. or less. The less the torque required, the higher will be the speed of operation until at no load the motor will reach a maximum speed of 560 rpm with full terminal voltage from the supply generator.

With the parallel system a single generator and the 400 volt motor cannot operate at all on a load requiring greater than 2800 lb. ft. torque—just about half the maximum torque of a series unit. Therefore, from the standpoint of being able to move the maximum load nothing is sacrificed in the series system if one of the two engine-generator units is down. This is a definite advantage.

From the standpoint of speed of operation on loads requiring torques well within the rated limits of the motors, the advantage is in favor of the parallel system. For example, at a torque of 1500 lb. ft. the series unit will operate at 525 rpm as compared to 850 rpm for the parallel unit. At approximately 2200 lb. torque the speed of operation of the two systems is exactly the same. But with sustained operation at this load, the parallel generator will show considerable heating whereas the series generator will be operating well within its rating.

As the number of generating units is increased above two, and on these large rigs there are four generators, the overall advantages considered from the standpoints of practical voltages, generator designs, standardization of parts, simplicity of control, and economics of application are in favor of the parallel system. The conclusions regarding the fields of application of the two systems are borne out by the large number of successfully operating units of both types.

Appreciating the fundamental electrical differences between the series and parallel systems of operation of generators, let us consider a comparison between steam and Diesel electric rigs of similar rating. To do this we shall first outline some of the characteristics of the better known steam equipment, and then give details on electrical apparatus that will produce comparable results.

Deeper drilling has necessitated heavier equipment. Today some of the steam apparatus in common use is 12 by 12 and 14 by 14 twin steam engines; 14 by 7½ by 18 and 15 by 8½ by 20 slush pumps. It is well known that a 14 by 14 twin drilling engine operating on 300 lbs. saturated steam at the throttle (350 lbs. at the boilers), will develop approximately 1500 hp at 400 rpm. A 15½ by 8½ by 20 duplex steam slush pump operating on 300 lbs. saturated steam at the throttle with full size liner and 900 lbs. mud

75 hp, 800 rpm, Mill type totally enclosed, forced ventilated, with explosion proof blower, direct current motor driving rotary table.

Variable voltage DC drive showing four wheel drawworks post control mechanism at drillers station on derrick floor. Also, ammeters indicating main motor load are shown in protective cases at right rear.

A battery of six 60 kw, 100 volt, direct current generators supplying power for a variable voltage drilling equipment of the Noble Drilling Company.

pressure will develop approximately 500 hydraulic hp at 50 strokes per minute. The smaller engines and pumps develop correspondingly lower horsepower with similar conditions of steam and pump pressures.

Naturally, if electric drive is to compete successfully with such steam equipment from such standpoints as time for making a round trip with the drill pipe, operating the mud pumps safely at their maximum permissible mechanical pressures and speeds, development of torque for moving stuck pipe, and other operations well known to experienced drillers, it is necessary to start with engine and generator capacities comparable to the aforementioned steam engines. The Rowan Drilling Company is currently operating on the Gulf Coast of Louisiana, two Diesel electric rigs of such capacities, drilling to depths of approximately 12,000 ft.

These variable voltage electric rigs operating on barges in the Mississippi Delta near La Fitte, Louisiana, employ the parallel system of operation and have engine generator capacity of 800 kw (1075 hp) for the main drives. There are four generators, each rated 200 kw, 400 volts, 40 deg. C. Two generators operating at 1200 rpm are belted and two generators operating at 600 rpm are direct connected to eight cylinder 9 by 12, 375 hp, 600 rpm Cooper Bessemer engines. The reason for using some belted and some direct connected generators is purely one of economics. Existing equipment was utilized in making up the barge unit. Mechanically it is preferable to use all generators direct connected to their respective engines.

Each of the main generators is equipped with a 25 kw, 125 volt, 40 deg. C exciter. On the two direct connected generators the exciters are mounted atop the generators and are driven at 1750 rpm through "V" belts from the generator shaft. On the two belted generators the exciters are direct connected to the generator shafts. The use of 25 kw exciters on each generator makes available not only for excitation but also for auxiliaries such as fans, blowers, wash down and shale shaker motors, pumps for engine cooling water, and lights a total of 100 kw at a constant voltage of 125 volts.

The slush pumps illustrated in the accompanying illustration of Rowan's barge-mounted rig are 7¾ by 18 each driven by a 400 hp, 2 bearing, 400 volt, 900 rpm, 40 deg. C forced ventilated motor through an overhung "V" belt drive using 18 "E" section belts.

The forced ventilated hoisting motor is continuously rated 400 hp, 400 volt, 900 rpm, 40 deg. C and drives the drawworks through a reduction gear (ratio 3.33) and chain.

The Diesel-engine generators, slush pumps and controllers are all mounted on an auxiliary barge which also has a slush pit built into it. Diesel fuel and fresh water are also carried in the hold of this barge. The remainder of the drilling equipment is mounted on the main submersible barge. Large power cables transmit the electrical energy from the generating units on the auxiliary barge to the several points of use on the main barge.

Knowing the capacities and arrangements of

apparatus on these large electrical rigs, it will be of interest to discuss the special inherent characteristics of generator and motor designs as well as the methods of control which combine to make variable voltage equipment so desirable for rotary drilling.

The generators are three-field machines — separately-excited shunt, self-excited shunt, and differential series—so proportioned that under any conditions of operation it is impossible to deliver more than a pre-determined stall current to the operating motors or to overload the engines. In fact reference to Curve A (Figure 2) shows that the engine load actually decreases as the armature current increases beyond the point corresponding to maximum generator kw for which the engines are applied. It is paradoxical that the engine is actually working more easily when excessive motor torque or hook pull is being exerted. However, there is no inconsistency when the system is considered as a whole. At the point of maximum kw on the generator, the armature current is approximately 1200 amperes. As the current further increases, the series field becomes preponderantly stronger, the terminal voltage is decreased, and the kw or hp (the product of volts and amperes) is decreased. Obviously, then, the engine can never be overloaded.

As the load increases the motor draws from the generator heavier current at constantly decreasing voltage (Curve B). As the voltage decreases, the motor speed decreases. At the same time the motor torque in line with an earlier statement that motor torque is proportional to its current, increases due to a predetermined maximum at stall due to the heavier current which it is drawing. This balancing of engine and generator capacity and the ability to obtain high torques without stalling the engine are important operating advantages of variable voltage equipment.

Of interest are the self-explanatory curves (Figure 3) which show the power delivered at several points in the variable voltage system from the engine shaft to the hook. Essentially, these curves represent efficiencies.

Both drawworks and mud pump motors are separately excited, of the shunt type, enclosed forced ventilated, with the explosion proof ventilating blowers mounted on top of the motors. The separately excited shunt fields on these motors provide two principal advantages:

(1) The motors are reversed as the applied armature voltage is reversed, necessitating only small generator field circuit contactors. This minimizes control cost.

(2) The motor torque will be always directly proportional to armature current, important where high momentary torques are required such as when pulling on stuck pipe.

Control is arranged so that any generator or combination of generators may be used on any motor

Two 200 hp, enclosed forced ventilated, direct current motors driving drawworks through twin pinion reduction gear.

Rowan Drilling Company's 400 hp, 400 volt, 900 rpm, 2-bearing, enclosed, forced ventilated, D. C. motor driving a 7¾ by 18 mud pump on a barge in the Mississippi Delta.

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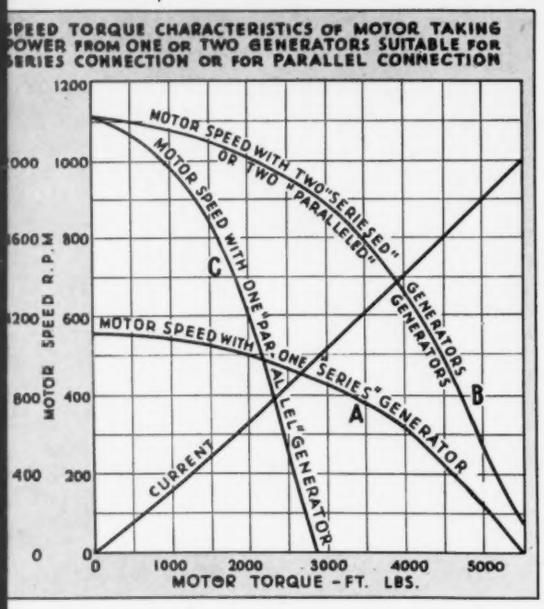


Fig. I

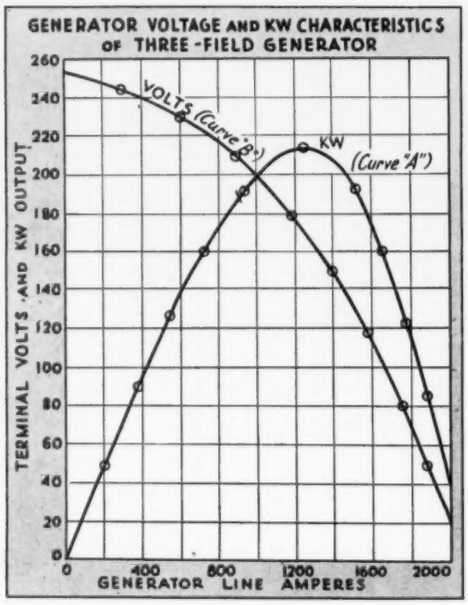
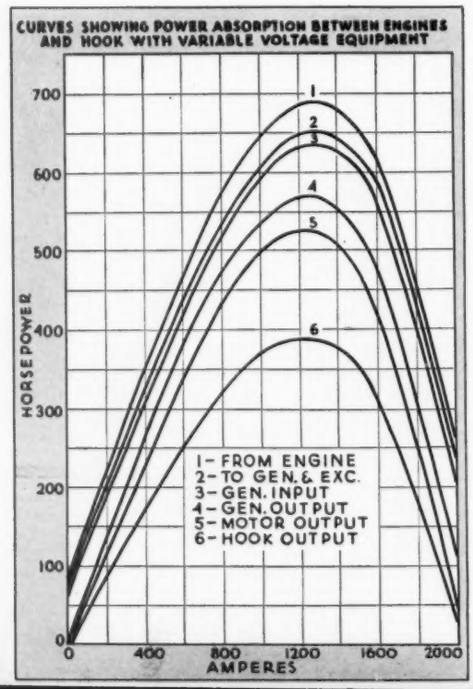
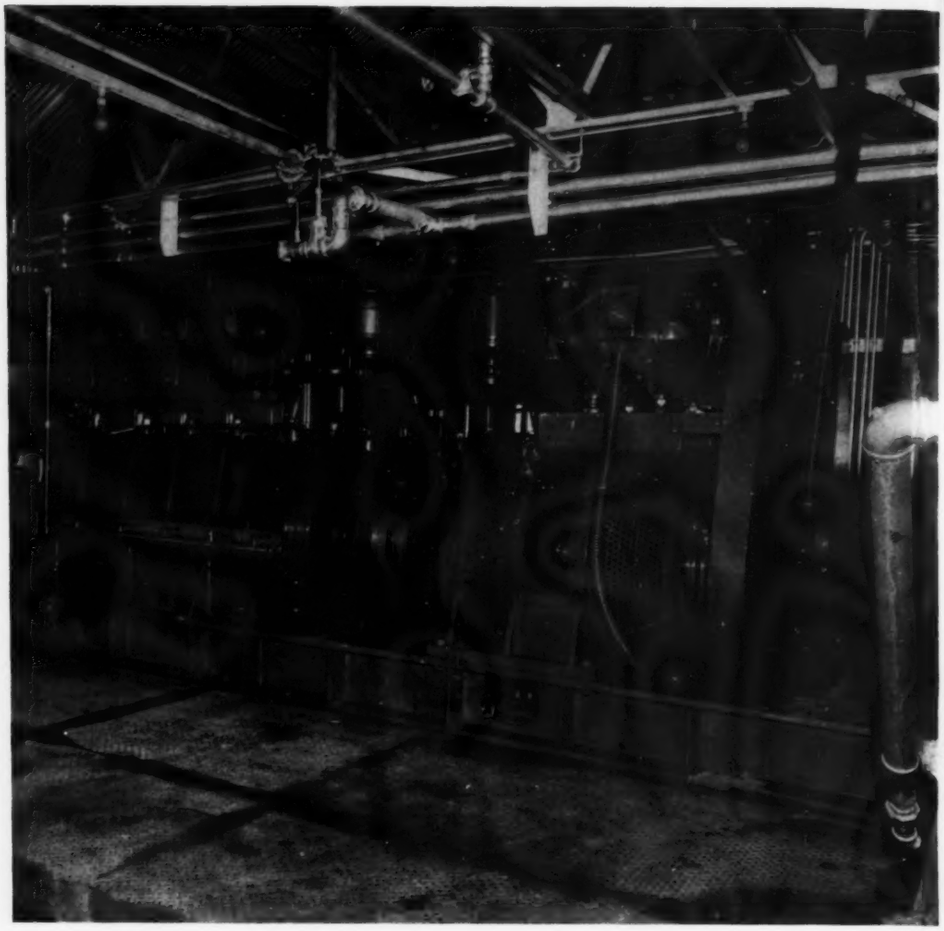


Fig. II

Fig. III





200 kw, 400 volt variable voltage generators with 25 kw exciter, direct coupled to 375 hp, 600 rpm engine in power plant, totalling 800 kw in main-generator capacity.

circuit, but in the normal drilling operation, two (200 kw) generators supply the 400 hp slush pump motor; one 200 kw generator is used for rotating; (this may be the drawworks motor or a separate table motor as shown in an accompanying illustration) and the remaining generator is used for a stand-by pump used to mix and stir mud so necessary in drilling operations in that locality.

When hoisting, three generators or 600 kw supply the present 400 hp drawworks motor. However, there is no reason why the full 800 kw cannot be made available to supply a single 800 hp or twin 400 hp motor on the drawworks. The arrangement of this twin motor drive is shown in an accompanying illustration.

All motor speed control and reversing are accomplished by the manipulation of small generator field currents which are handled directly on a drum controller with a large number of speed points. These master controllers shown mounted on the sides of the resistor racks are operated from the driller's position on the derrick floor as illustrated. Each of the four wheels controls one generator, and may be so interlocked that one, two, three, or four generators may be operated simultaneously with manipulation of but a single wheel. Besides this, it is possible for the driller at his usual position merely to press a button to operate selector switches which change connections from drilling to hoisting and vice versa. Also an emergency stop button within easy reach of the driller disconnects all motors from their power supply circuits, a feature which assures maximum safety. Meters visible to the driller indicate the load on the draw works and mud pump motors at any time.

Thus all operations on the rig are immediately under the supervision and direct control of the driller—features which fulfill the claims of flexibility and reliability.

Economy is an item of special consideration, and for this particular locality is in favor of the Diesel electric rigs when compared to steam. Most of the wells in the Gulf Coast Louisiana fields are of low gas/oil ratio with no sufficient quantity of gas available for fuel purposes; consequently a great saving in fuel is effected by the use of engines as opposed to the use of oil fired boilers for steam drives. Another appreciable saving to the driller is in the amount of fresh water required. All fresh water must be transported to location over long distances by barge. It remains only to contrast the amount of fresh water required in the engine water jackets for cooling with that required for boilers when steam equipment is used to realize the tremendous advantages in favor of the Diesel electrics.

Drilling unit with 10 in. by 9 in. vertical steam engine direct connected through a two-speed gear-box to the rotary table, manufactured by Oilwell and in use in California.

FACTORS Effecting the Choice of Rotary Drilling Equipment

By V. J. Beissinger

Richfield Oil Corporation

Rotary Drilling Equipment is Selected on the Basis of Cost and Available Power Sources in Relation to Anticipated Drilling Problem — Author Suggests Operators Pool Drilling Records.

ROTARY drilling outfits may be selected on the basis of an analysis of three major factors:

1. Program, as determined by future production economics.
2. Power, as selected on the basis of local or areal economics.
3. Cost, as resolved in terms of economic useful life.

The streamlining effect on the economic status of the industry already has influenced the nature of the mechanical considerations. The human desires of management can best be satisfied today by the investigation and selection of the material means best suited to the handling of many varied rather than one specific job. Qualitative and quantitative adaptation is the characteristic which can be built into a rotary drilling outfit so that its selection can be justified by the range of jobs it can handle. Thus, the requirements of the drilling program must be the first factor to be considered.

Drilling programs are shaped by the factors which influence the choice of hole and casing sizes. The choice of these is influenced in turn by such local factors as depth, formation, attitudes of strata, expected productivity, well spacing, and the number of wells to be drilled. Furthermore, there are three general types of holes which influence the economics of the selection of suitable drilling programs: Core holes, wildcat or exploration holes, and regular development wells.

For all practical purposes, the drilling program is a major mechanical problem. Up to date, it has been the practice to obtain ever bigger outfits to handle ever deeper drilling programs. This occurred because the deeper wells were drilled in accordance with hole and casing size

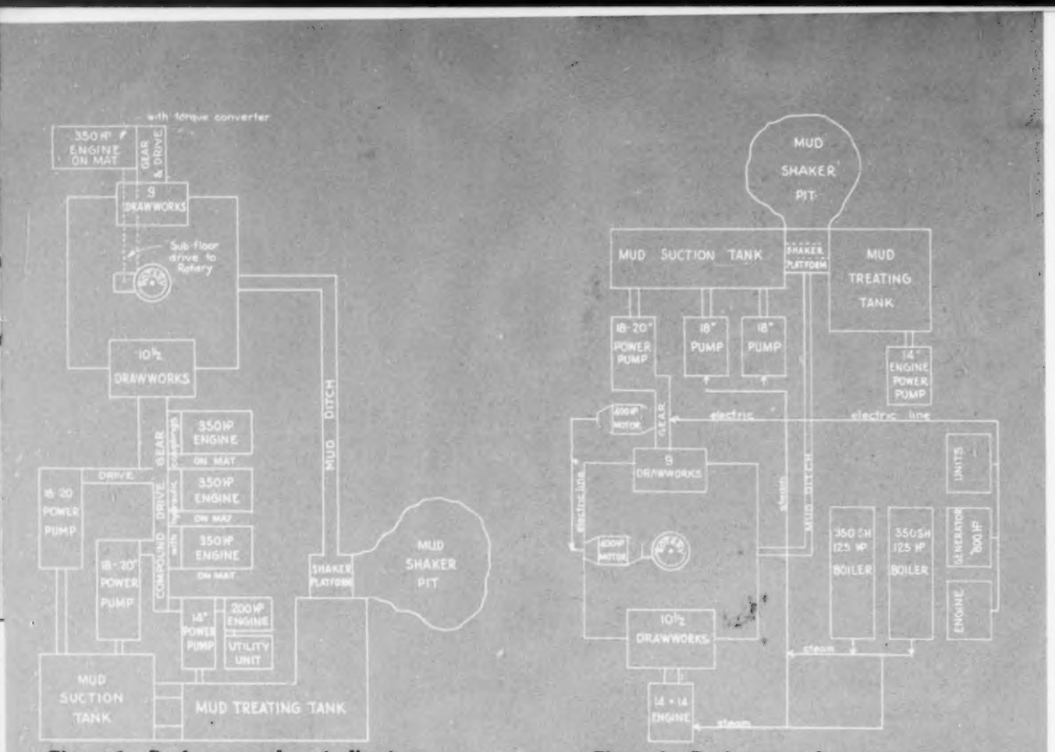


Figure 1. Dual purpose layout, direct mechanical rotary outfit, for deep drilling. For shallow drilling and slim hole wildcats use No. 9 drawworks and engine unit with one 18-20 in. and one 14-in. power pump engine unit as independent rig.

Figure 2. Dual purpose layout, steam-electric rotary outfit, for deep drilling. For shallow drilling and slim hole wildcats use electric units as independent rig with No. 9 drawworks and standby engine power pump.

programs as specified for their shallower predecessors.

For example, a 13⅜, 8⅝, 6⅝ casing program for an 8000-foot development campaign was extended to a 10,000-ft. field. The use of 5 $^{9}/_{16}$-in. drill pipe was extended from 6000 ft. to 9000 ft. of depth within the past 10 years. In order to handle such progressive load increases, machinery and equipment was redesigned. Manufacturers and supply companies crowded one another to be the first on the market with bigger, heavier, and costlier outfits. For the shallower holes, nevertheless, the small outfits still were required. So we find an industry in a position of rare economic servitude, under which the cost of drilling became a function of many human desires for material diversification.

Recently, however, the streamlined drilling program has been advanced as a means of simplification. Its beginning was in the Mid-Continent fields as the direct result of economic pressure. This was due to the effect of legalized curtailment of production and consequent reduction of income to be obtained from the sale of oil and gas. So-called big outfits were available to handle the deep well drilling loads, but the pay-out period was so lengthened that expenditures for this costly equipment, as well as for the larger sizes, heavier weights, and special alloy grades of required tubular goods, could not be justified. The economics of selection was resolved into a proposition of adaptation. The outfits on hand were called upon to handle the deep well programs in order to follow up and keep pace with discoveries. Smaller holes were drilled to accommodate smaller casing strings. A new type of outfit appeared powered by multi-cylinder internal combustion engines. Spreading to California, the slim hole idea caught on, and it is apparent that much argument is yet to be presented prior to its more general acceptance.

It is our point of view that there is an optimum drilling program which can be handled by a few types of outfits with capacities based on some sort of standardized range of application. Naturally, such an idea must be adopted by agreement. If it is the desire of management to obtain such material satisfaction, with respect to the selection of rotary drilling equipment, the manufacturers and suppliers will be pleased to cooperate. In this paper we shall attempt to point out merely the essentials of a discussion which we feel can be concluded only after considerable investigation.

Basically, we suggest that the approach to the study of the industry's drilling equipment needs should follow the same general path as that which led to such good results in connection with the simplification of casing lists. We can set up the types of equipment now available to the industry by sizes and capacities. The elimination of superfluous groups can be based upon the adoption of range limits.

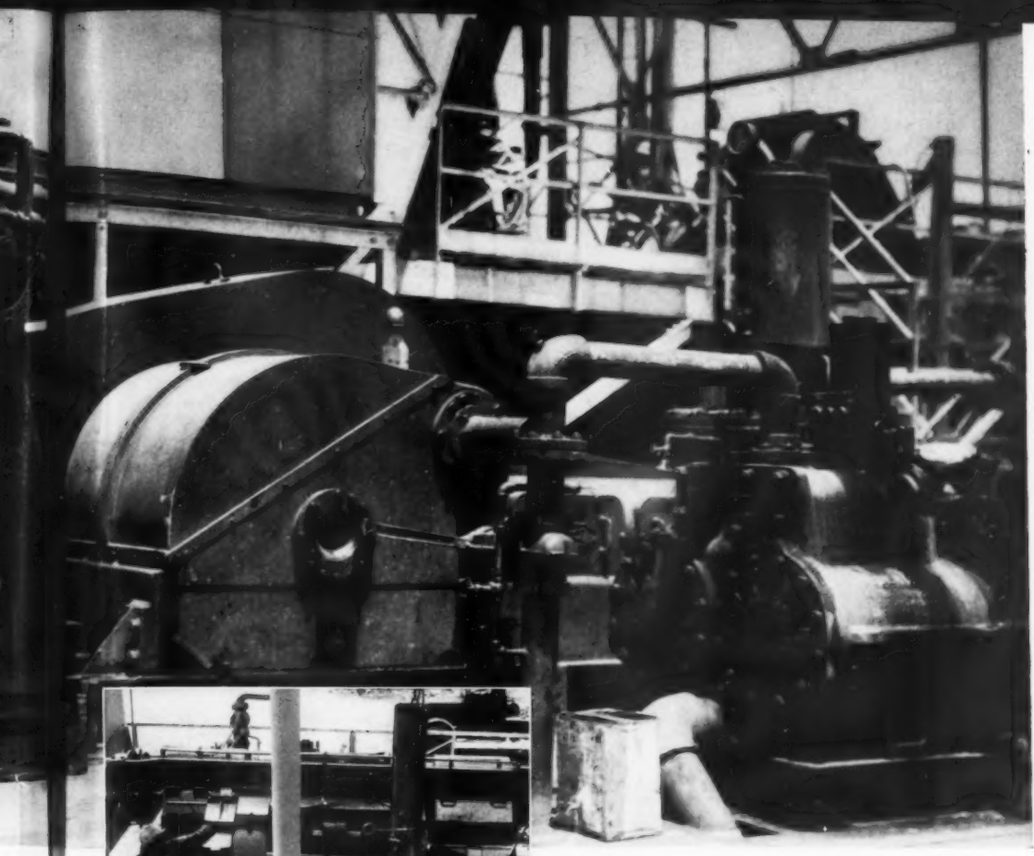
Manufacturing ingenuity will not be affected in the least because the application of designs and devices then can be promoted on the most logical thesis of competition, namely, a better way to obtain a certain range of performance.

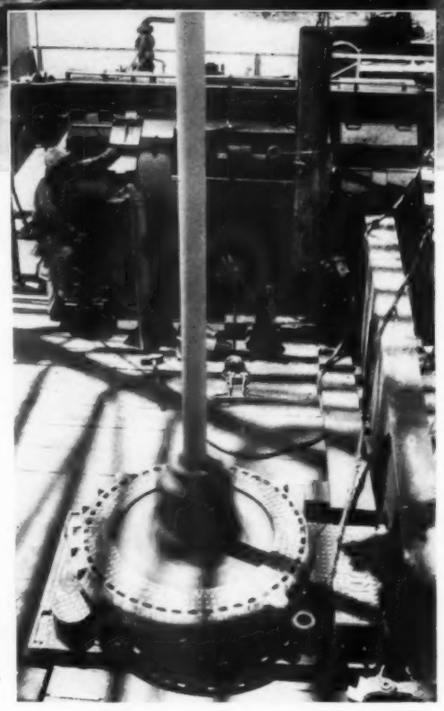
The net result will be standardization on the broad basis of group selection, rather than upon the theory of mass production of similar parts and replacements. The latter conception of standardization is desirable, but obtainable only upon the conclusive delineation of the former, and is an ultimate rather than an immediate aim. The development of such an idea can be explained in relation to the three types of drilling work to be considered.

Of minor mechanical importance, because of limitations to rather shallow depths, and also because of the premise of being drilled purely for geologic information, are core holes. Relatively small, self-contained, portable outfits are utilized for this work. These are engine-powered, gas, butane, or Diesel, unitized and truck mounted, with mast, pump, hoist, rotary, and other accessory drilling equipment. Fuel tanks are carried with the unit, and the low rate of water consumption makes it possible to haul economically when necessary.

Exploration hole requirements differ from regular development work in one respect, that is, by degree of isolation. Further drilling in the vicinity depends upon discovery. On a one-hole basis, there is no need for an elaborately planned program. Streamlined wildcats are now the rule rather than the exception. Thus, the selection of a rotary outfit for wildcat drilling should be based upon the economics of the power factor firstly, with the expansion of this consideration to provide adequately for all the other subordinate factors of depth, formation, and size of hole.

Rotary outfits are rated on the basis of depth capacities by most all the manufacturers. If such





Making hole with a chain driven rotary.

The old and the new power and direct driven steam slush pumps. Both perform more work with increased depth of operations, and consequent smaller diameter holes and drill pipe strings.

ratings are based on more or less reliable engineering data, the choice of an outfit is obviously an easy matter. The remaining consideration is the cost of the power required to perform the work. The fact that different manufacturers do not agree on the criteria which should be used to rate an outfit with respect to its capacity to drill to a given depth is sufficient evidence that there is need for the establishment of standards. Regular development work requires the drilling of given areas to comparable depths after a planned pattern of hole and casing sizes based on the average economic significance of each well completion. If fuel and water are plentiful, steam outfits can be utilized. These utilities, however, are never so plentiful as to permit wastage. If gas can be saved in the productive formation, its indiscriminate use for drilling fuel cannot be excused. The examples of direct mechanical and electric rig operations in oil fields from Illinois to California show a continuity of growing favor among drilling contractors. The fuel and water economies effected by such rigs are well known. If gas can be saved to lift more oil for more economic future production, the cost of such gas for fuel may be said to be at least doubled.

Drilling equipment for regular development work need not be catalogued separately from that which may be recommended for wildcat operations. The automobile industry provides the public with a variety of truck models and capacities; the truck purchaser attempts to select a model and capacity which will handle the greatest number of different jobs economically. The writer has seen dump trucks hauling rock, sand, rotary mud clay, grapes, oranges, and grapefruit. By the same token, a rotary drilling outfit may be built up or down as required.

This can be illustrated best by sketches as shown on Figures 1 and 2, which illustrate the manner in which a deep well drilling outfit can be split for service in shallower drilling without much expense. Similarly, a small outfit can be built up to deep well drilling capacities. In this case, the purchase of heavy duty rotaries, swivels, blocks, and other accessories would be additional. Drilling programs influence the selection of rotary equipment to the extent of the subordinate effect of a combination of peculiarly localized factors. Depth—a 12,000-ft. hole can be drilled with the same outfit that drilled a 9000-ft. hole, provided casing and hole sizes are revised in relation to known performance capacities.

Formation—the size and capacity of drilling equipment is secondary to the operating skill and knowledge of the subsurface stratigraphy of the driller.

Expected productivity and well spacing—there is conclusive evidence that drilling practices rather than drilling equipment influence the indices of productivity. It is argued that heavy duty equipment facilitates the promotion of optimum drilling practices for this purpose. Time drilling appears to be the most critical factor involved. However, recent bit and drill pipe advancements have been shown as the real factors, because drilling time is governed primarily by

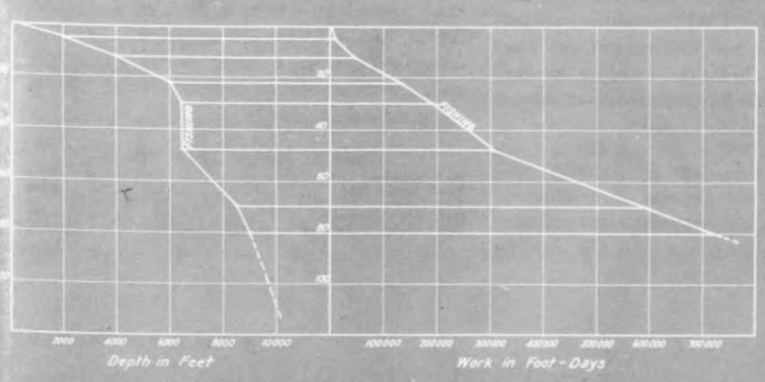


Figure 3. Drilling work accumulation in relation to drilling depth and time.

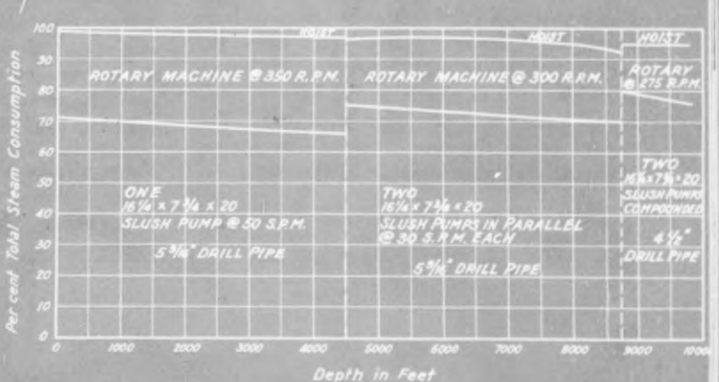

Per cent Total Steam Consumption
HOIST
ROTARY MACHINE @ 350 R.P.M.
ROTARY MACHINE @ 300 R.P.M.
ROTARY @ 215 R.P.M.
ONE 16 1/16 x 7 3/4 x 20 SLUSH PUMP @ 50 S.P.M.
5 1/16" DRILL PIPE
TWO 16 1/16 x 7 3/4 x 20 SLUSH PUMPS IN PARALLEL @ 30 S.P.M. EACH
5 1/16" DRILL PIPE
TWO 16 3/4 x 7 3/4 x 20 SLUSH PUMPS COMPOUNDED
4 1/2" DRILL PIPE
Depth in Feet

Figure 4. Relative steam power distribution vs. drilling depth. From data of actual steam consumption tests 350 lbs., 100-150 degrees F. superheat.

the skill, efficiency, and control by men at the surface of subsurface equipment. The number of wells to be drilled obviously is a factor which governs the initial need for a rotary outfit.

The depreciation of drilling equipment may be spread over a series of drilling programs. Most outfits are retired and junked because they are obsolete. Depreciation charges which finally overtake a rather unpredictable obsolescence factor are the objective of the calculations of most engineers. Thus, the recommendation of drilling equipment must be based upon the surety of its capacity. The operation of such machinery under the stress and strain of overloads hastens its obsolescence because it may be rendered unfit for long-lived utility far in advance of reasonable depreciation allowances.

Fair value to all concerned is the selection of equipment commensurate with an expected range of useful life which may be spread over a series of drilling programs for a period of at least four years, with enough overload capacity to provide a reasonable margin of mechanical safety. There are at this time many good rotary outfits in 8000 to 10,000-ft. drilling well campaign service over eight years old. The cost of a drilling program in terms of equipment value is often less than the cost of a drilling well. That is the economic justification for the drilling of wells by contract. Power is the second factor which influences the selection of rotary drilling outfits. Power generation and utilization share equally effective economies. Characteristically, there are a number of subordinate factors which influence the choice of power. These are in the order of importance:

1. **Source and accessability.**
2. **Dependability.**
3. **Capacity.**
4. **Efficiency**

Necessarily, all four of these factors may be resolved into terms of cost. The economic significance of the power factor is a function of the work to be done. Thus, a wildcat project presents a set of conditions which upon abandonment automatically cease to exist. However, in the event of discovery, these conditions may be amplified and expanded considerably.

The essential facts in connection with the cost of power are well known. Fuel and water are the necessary utilities. Rotary drilling outfits may be adapted to the use of three types of power: Steam, electric, and direct multi-cylinder internal combustion engine. Today all three are industrially acceptable.

Steam generated in oil field boilers requires large quantities of dependable reserves of water and fuel, either gas or oil. These must be transported by truck or pipe lines. The cost of hauling such utilities is very often prohibitive. The cost of piping the same from reliable reserves is usually the determining practical factor.

The cost of utilization or efficiency of the boiler plant, as well as individual units of drilling equipment, is significant. Boiler plant installation costs are often prohibitive due to topographic conditions.

Chief advantage of steam power is the fact that its use permits the employment of rotary drilling outfits generally on hand, and, therefore, obviates the necessity of looking around for other types of equipment. Furthermore, the average rotary crew is at this time more familiar with steam power equipment.

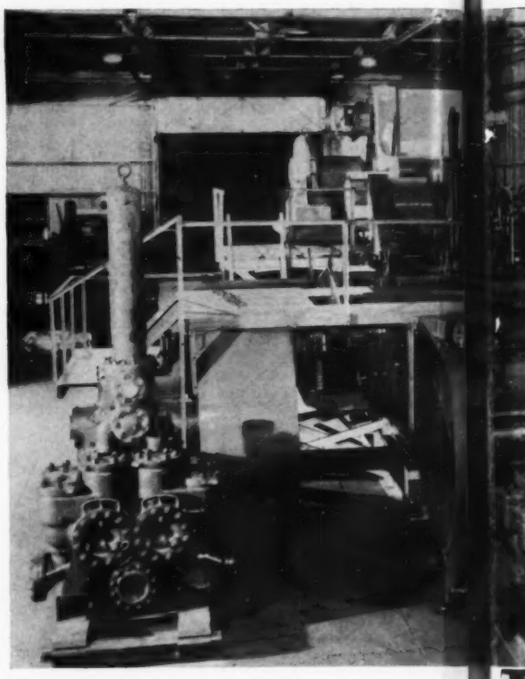
Electricity may be obtained through power transmission lines or by means of engine operated generator plants. For the drilling of a wildcat well the former is often too costly. Engine powered generator plants, however, are becoming more and more popular, particularly in the Mid-Continent areas. The load and torque features of direct current motors have been proved the equal of steam equipment, and may be utilized at the rigs with similar operating characteristics. The cost of electric power is largely a function of the quantity of energy required from the generator plant. Engines and generators represent considerable weight, and for hauling and installation require almost the same attention as an ordinary boiler plant, with one distinct exception, namely, the elimination of pipe, valves, and fittings for fuel, water, and steam.

Direct engine power is the simplest of all three. The use of multi-cylinder internal combustion engines for drilling outfits is also the least advanced because it has been developed over a much shorter period of time. There is also the nuisance factor of pulleys, V-belts, chain, clutches, and gear mechanisms, which attached to the mechanical outfit constitute the main reason for much of the prejudice which handicaps its more general acceptance. Nevertheless, the use of direct mechanical outfits for both wildcat and development drilling has demonstrated beyond doubt, certain distinct economies which have lowered the cost of drilling. Criteria such as these have resulted in a sudden spurt in the demand for this type of equipment.

The cost of direct engine operated outfits is influenced chiefly by the ease with which such rigs can be moved, rigged up, and torn out, as well as by the elimination of much weight, fewer large bulky units, and substantially lower fuel and water consumption. As in the case of the electric outfit, pipe, valve, and fitting requirements are reduced to a minimum. Generator losses are probably equivalent to the transmission losses of direct mechanical rigs, although the direct current outfits still hold the distinct advantage of more desirable power characteristics. The development of the hydraulic coupling, torque converter, and a hydraulic transmission will eliminate this handicap.

Power dependability is most satisfactorily obtained within a rig site location of a self-contained plant. Thus, the generator plant and the engine layout of the direct mechanical rigs are typical of maximum power dependability, provided there are spare engines and generators for emergency service. In developed fields, the reliability of a gas and water supply is determined by the nature of the production and the ability of the field personnel to keep planning apace with the anticipated work.

The capacity of fuel gas production to keep up with development drilling is often a factor. Under the terms of a curtailing agreement, it can be shown that a costly shortage of gas might result. Similarly, the adequacy of a water supply might be affected by the vagaries of water well production methods, a recession of the water table, or even a very cold night.



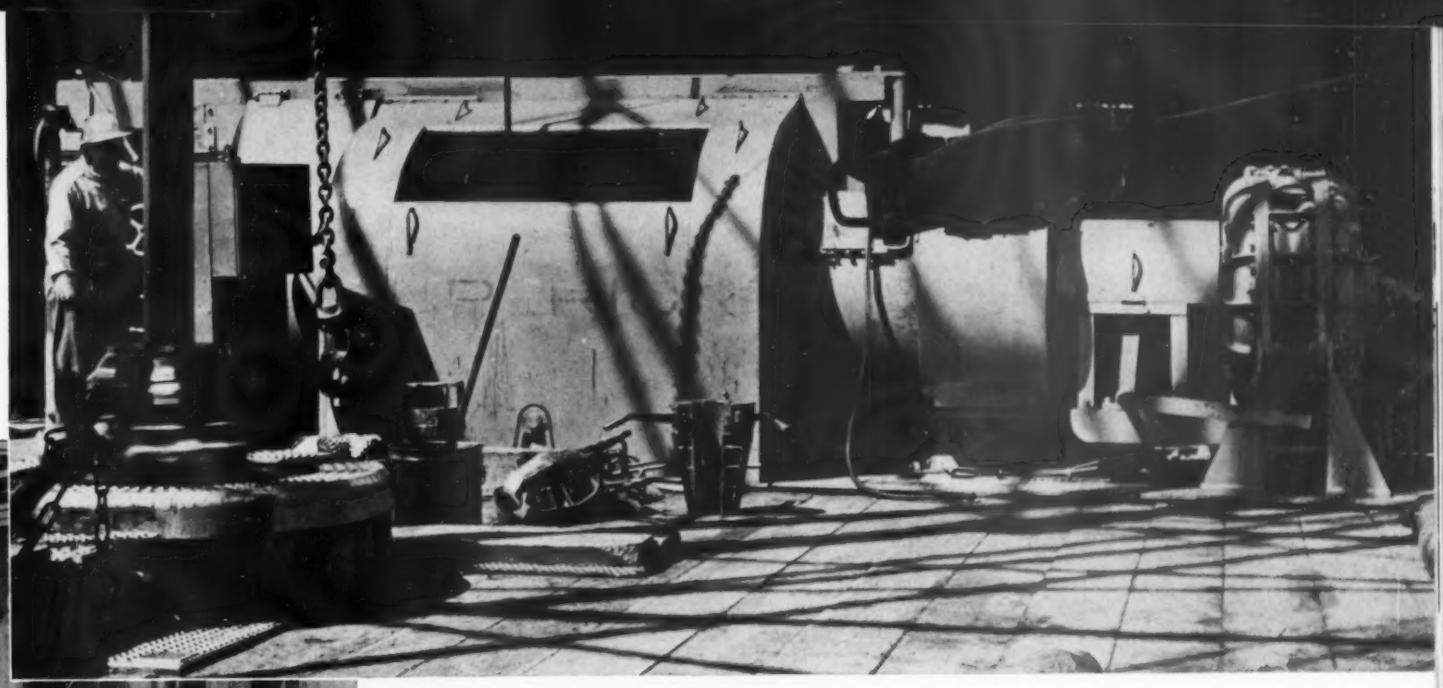
Internal combustion engine powered slush pumps with well guarded transmission drive for safe clearances.

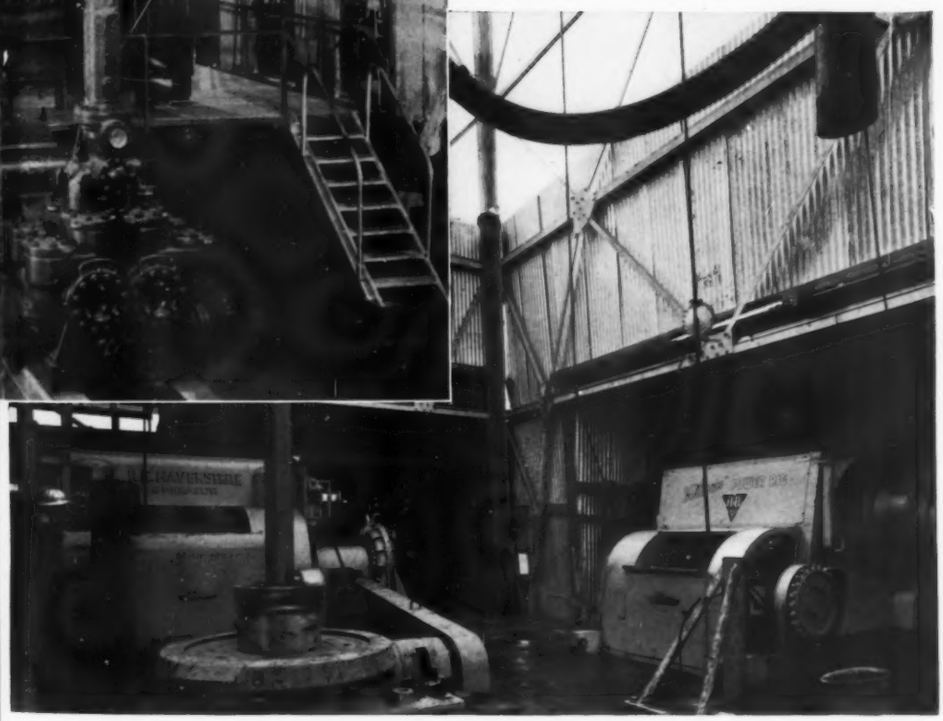
Efficiency of power generation and utilization is as controversial as the calculations which might be made to prove the points of argument. For the purpose of this paper, we shall dismiss such abstruse computations and substitute a more tangible conception, namely, cost.

For example, we shall set up an actual case of nine wells, drilled in a developed field, in the same general area of that field, to comparable depths, with the same casing programs, by three crews using three different power plants, two steam, and one direct mechanical, and all rigs using natural gas fuel.

Crew I. 250-Lb. Steam Plant

Well Number	1	4	7
Total Depth (ft.)	9,225	9,150	8,980
Total Days	70	56	56
Mcf. Gas Consumed	39,076	36,306	38,508
Bbls. Water Consumed	108,129	93,959	98,693





Making hole without benefit of steam.

Making hole with a big steam outfit. Here we show hoisting, braking, and rotary machinery all engaged in the performance of work which with increased depth of operations grows progressively more burdensome.

Crew II. 350-Lb. Steam Plant

Well Number	2	5	8
Total Depth (ft.)	9,350	8,980	9,050
Total Days	76	57	62
Mcf. Gas Consumed	48,882	48,962	47,083
Bbls. Water Consumed	136,973	114,550	118,541

Crew III. Three 350 Hp. Engines

Well Number	3	6	9
Total Depth (ft.)	9,025	9,100	9,190
Total Days	70	50	67
Mcf. Gas Consumed	5,426	3,913	6,095
Bbls. Water Consumed	31,747	35,815	36,243

The out-of-pocket operating efficiency of these three setups may be said to be somewhat in proportion to the value of gas and water consumed, plus the cost of rigging up, tearing out, and moving. This is the kind of efficiency rating which interests management and stockholders.

Naturally, any serious differences in drilling time might influence other drilling costs to the extent that the cost of power might be less important. However, as indicated in the foregoing actual case, such differences in drilling time may be the result of crew and supervision.

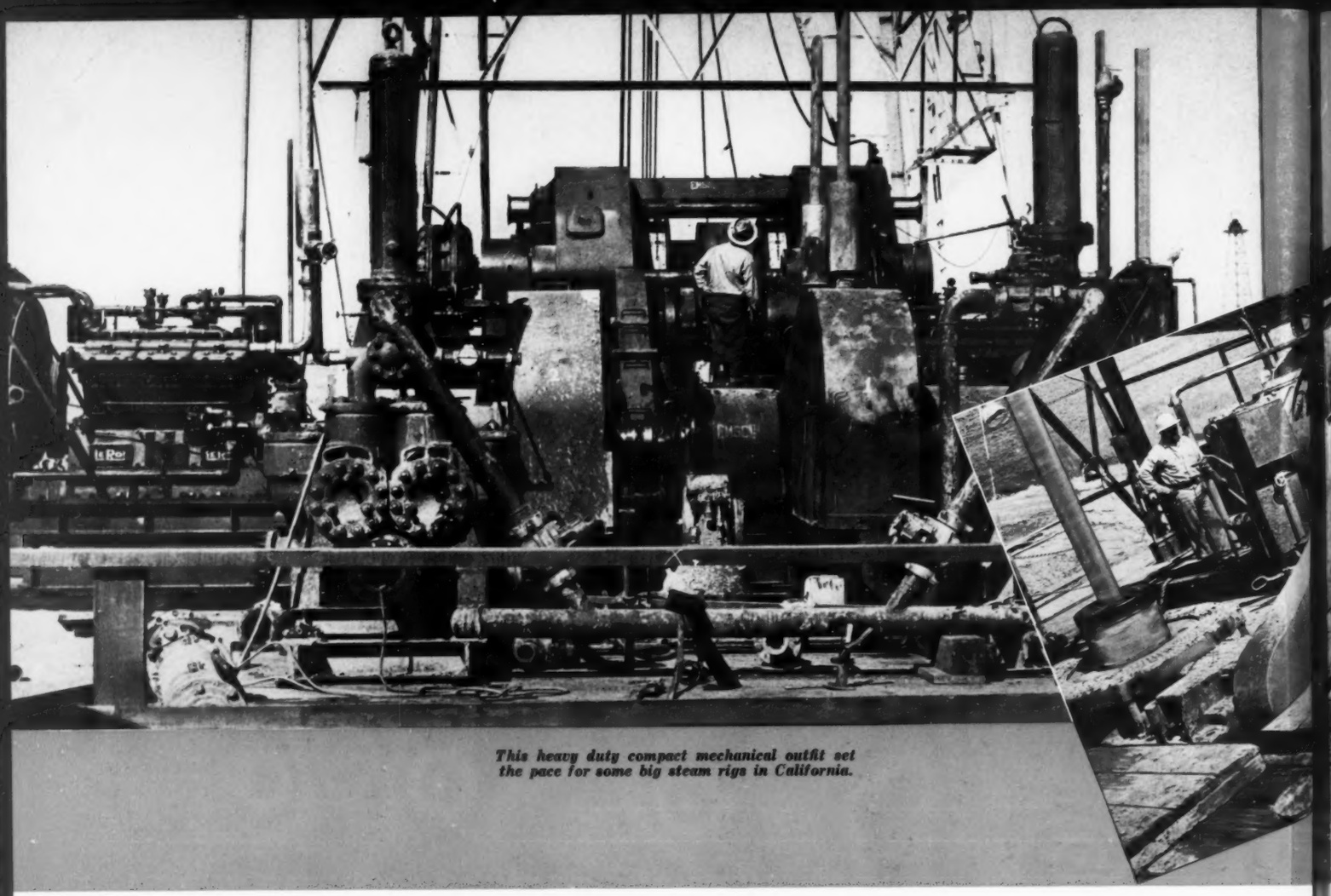
For all practical purposes, the direct mechanical rig operated satisfactorily on about 11 percent gas and 30 percent water consumption when compared with the two steam operated rigs.

Individual units of drilling equipment have characteristic power ratings in terms of consumption.

Well known to oil men is the fact that two similar operations can be handled by two different pieces of equipment of the same rated capacity, but with widely divergent power consumption features.

In order to ascertain the nature of such variations in oil field drilling equipment, one company conducted a lengthy series of tests during the drilling of one of its deeper regular development wells. The purpose of these tests was to obtain only the basic steam consumption data for the benefit of future engineering reference and application. Comparative equipment tests and trials were not attempted. Substantially valuable information was disclosed as outlined:

Boiler Plant: Five 350-pound superheat steam generators with forced draft to stacks. Integral type superheaters furnished degree of superheat as function of load up to about 150 deg. F. at 50,000 pounds steam per hour.
Drilling Equipment: 14 by 14 twin cylinder hoist engine; 10 by 9 vertical rotary drive engine; 12 by 12 twin cylinder standby engine; heavy duty 4-speed drawworks; 3-shaft 30⅝ by 41-inch drum, 10-inch drum shaft; two 16¼ by 7¾ by 20 slush pumps; 27½-inch oilbath rotary machine. Balance of accessory equipment all heavy duty, with hoisting apparatus using 1¼-inch wire line.
Hole Drilled: 18-inch to 1435 feet (cemented 13⅜-inch casing); 12¼-inch to 8420 feet; 11-inch to 9430 feet (cemented 7-inch casing); 6-inch to 9790 feet.
Duration of Steam Tests: 61 days.
Average Steam Consumption: 487,500 pounds per day.
Average Gas Fuel Consumption: 808 mcf. per day.
Peak Steam Consumption: 570,000 pounds per day from 7000 feet to 8000 feet with 5$^{9}/_{16}$-inch drill pipe, and 420,000 pounds per day



This heavy duty compact mechanical outfit set the pace for some big steam rigs in California.

from 8800 feet to 9400 feet with 4½-inch drill pipe.

Minimum Steam Consumption: 250,000 pounds per day at 500 feet with 5$^{9}/_{16}$-inch drill pipe, and 240,000 pounds per day at 9700 feet with 3½-inch drill pipe.

Minimum Gas Consumption at boilers also followed above trends.

Slush Pump Steam Consumption: Maximum 60 pounds per fluid hp. hour at 50 strokes per minute; Practical Minimum, 38 pounds per fluid hp. hour at 25 strokes per minute; Observed Optimum, 40 pounds per fluid hp. hour at 30 strokes per minute. It was demonstrated that one pump operating at 50 strokes per minute required about two percent more steam than two pumps operating in parallel at 30 strokes per minute each.

Rotary Drive Steam Consumption: Maximum, 18,000 pounds per hour at 380 rpm.; Practical Minimum, 3600 pounds per hour at 130 rpm.; Observed Optimum, 7800 pounds per hour at 260 rpm.

Hoisting Engine Characteristics (from series of typical hoisting curves): Low-low, 830 to 840 net hook hp. for handling 176,000 to 200,000 pounds net hook load; High-low, 710 to 780 net hook hp. for handling 108,000 to 176,000 pounds net hook load; Low-high, 620 to 720 net hook hp. for handling 66,000 to 108,000 pounds net hook load; High-high, 325 to 540 net hook hp. for handling up to 66,000 pounds net hook load.

It is noteworthy that the power required for hoisting was tertiary to that which was required for circulating and drilling work. Inferentially, the greatest power economies can be realized by slush pump and rotary machine operating improvements. The foregoing data are a clue to the answer of a common question—how much power is required to operate a given set of drilling equipment in actual service?

The cost of power utilization naturally determines the trend of the cost of power generation. Net effective utilization costs are the final measure of plant requirement and generating costs. It is the writer's conviction that there exists in the files of many companies a wealth of drilling equipment operating data which, if gathered together and correlated, would provide a substantial nucleus around which we could build a system of engineering values for the selection of drilling equipment on the basis of operating characteristics. An accumulation of facts like this would obviate forever the necessity for so-called expert conjecture and highly opinionated recommendations. Power factors can be evaluated with remarkable accuracy, and it is only the lack of convincing and overwhelming local and regional statistics which handicaps the full use of their economic application.

Thirdly, and all-inclusive, among the principal factors which influence the selection of drilling equipment is over-all cost. The economics of selection is most finally explained by the formulae for cost determinations. These formulae are influenced profoundly by individual company constants. Such constants are sometimes the reflection of corporation bookkeeping practices.

Obviously, engineers must resort to more arbitrary methods of cost analysis. Fundamentally, these engineering methods are empirical and depend largely upon the keeping of good performance records. Records which tell the story of the performance of drilling equipment are only as valuable as they are complete. Partial data automatically opens the way for colored information and biased opinions.

Objectively, the conclusion of any cost analysis should be able to stand on its own merits. We propose, therefore, a standard group of cost items which we believe to be adequate as indicators of the cost of drilling. Such a cost aggregation cleaves into three general classifications:

I. Tool rental charges.
II. Drilling expense.
III. Well investment.

Drilling machinery and equipment belongs in the first category. It cannot be charged as expense to any one job under ordinary and accepted procedures. The cost of drilling equipment is spread out over a number of years of useful life, and is prorated back to the properties and wells in some proportion to the relative amounts of service rendered. It is the nature

and composition of such tool rental charges which could be standardized on the basis of industry experience, as well as upon individual company data. Firstly, a complete list of acceptable tool rental items must be agreed upon. We suggest the following:

1. Drilling derrick and derrick accessories.
2. Boilers and unitized boiler plant equipment.
3. Electric generators and motors.
4. Engines.
5. Pumps.
6. Draw-works and brakes.
7. Rotaries, swivels, blocks and crowns.
8. Standby units.
9. Blow-out preventers and control equipment.
10. Drill pipe, drill collars, stems, subs, elevators, tongs, slips, weight indicators, and fishing tools.

All other items used in connection with drilling well operations can be considered as either expense or investment, neither of which are the concern of this paper except insofar as they may be affected by their tool rental relationships. Secondly, there should be an agreed range of capacities for not more than three sizes of rotary outfits, based, for example, on a dual load rating, shaft and drive capacities for hoist work, and drive and transmission capacities for drilling work.

1. For drilling to 5,000 feet.
2. For drilling to 10,000 feet.
3. For drilling to 16,000 feet and deeper.

Thirdly, the establishment of a standard measure of performance to be used as the basis of charges would promote more useful uniformity of procedure. The performance unit in terms of individual well work could be a compound expression of both depth and time. Drilling work thus can be illustrated and very closely approximated by the foot-day. A uniform procedure could be based upon a study of California drilling records for California use factors, which in turn would be complemented by agreed standards of economic useful life. Obviously, it is agreed that different pieces of drilling equipment vary considerably in terms of useful life.

The necessity for the application of a weighted average system of control is apparent. The foot-day unit is well suited for such an adaptation. An example to illustrate the manner in which the foot-day drilling work system may be utilized to spread and equitably account for tool rental charges is outlined below:

Total cost of new drilling equipment (one rig)	$150,000.00
Less estimated salvage value at 10%	15,000.00
Net depreciable cost	135,000.00
Plus 35 percent for repairs and maintenance	47,250.00
Total cost of tool rental items	182,250.00
Estimated economic useful life:	
Number of wells drilled	15
Av. depth of wells drilled (ft.)	9,000
Av. days drilling per well	55
Number of foot-days	7,425,000
Tool rental charge per foot-day	$0.025

For comparative analysis, the tool rental rate per drilling day would amount to $220, and per foot of drilled hole to $1.35, on the basis of the same useful life estimate. The estimate of useful life is the figure which could be obtained from a conclusive resume of drilling experience data. It should be a weighted average of the economic useful life expectancy of the major drilling equipment items, as listed hereinbefore. The accumulation of such records should be no more difficult than the gathering of production statistics, and should be equally advantageous to all concerned because:

1. They would serve as a basis for more comprehensive depreciation studies, and
2. Would provide the data to substantiate a more systematic repair and replacement policy.

There are many drilling operations during the course of which no new hole is drilled. Because the drilling equipment is utilized whether or not hole is made, and because the foot-day unit is weighted for both depth and time, it is possible to spread most equitably such charges as tool rental, which, in themselves, are useful only insofar as they may reflect, as closely as possible, actual drilling experience. A typical drilling job will illustrate the point. In this case, trouble was encounted at 6420 feet, and for eighteen days, no new hole was made.

Accumulated Tool Rental

Factors			Charges		
Depth	Time	Ft. Days	At $1.35 Per Ft.	At $220 Per Day	At $0.025 Per Ft.-Day
2,000	5	10,000	$2,700	$1,100	$250
4,000	12	48,000	5,400	2,640	1,200
6,000	22	132,000	8,100	4,840	3,300
6,420	30	192,600	8,667	6,600	4,815
6,420	48	308,160	8,667	10,560	7,704
8,500	70	595,000	11,475	15,400	14,875
9,000	80	720,000	12,150	17,600	18,000

Noteworthy are the following disclosures:

(1) Tool rental charges on a foot-day basis accumulate so that the lowermost portion of the hole is weighted most heavily. Drilling experience proves that this feature more truly approximates the actual progression of drilling costs than the usual straight line methods. Because drilling experience is a progression of actual work quantities as reflected by rotating, hoisting, and pumping operations, and because the accumulation of such work is possible only in terms of foot-pounds, or other such characteristically defined work units, the foot-day unit is peculiarly analogous. Drilling costs increase in proportion to the drilling work done, and in order to obtain the most characteristic increments of progression, both depth and time factors must be combined.

(2) During the eighteen day no hole period, there is an appropriate tool rental charge which reflects nominal machinery and equipment operations, whereas on a footage-basis, no charge is shown, while on a day basis, the charge is excessive for the type of operations involved.

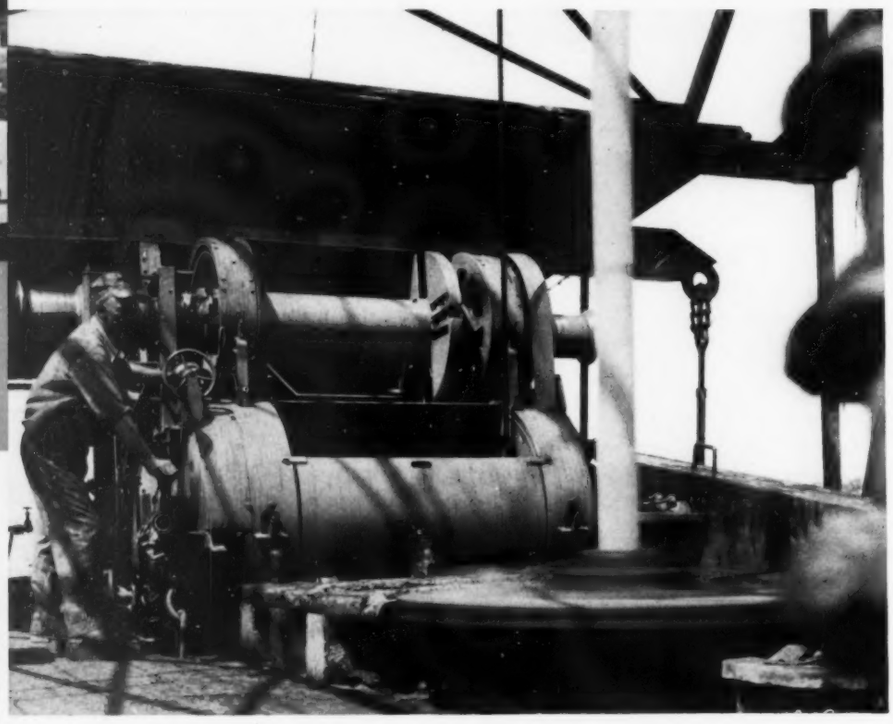
(3) The foot-day method is applicable to any depth of hole drilled within the total depth capacity of the largest heaviest duty outfit. One rate is, therefore, adequate for all types of equipment on a weighted average basis. Correspondingly higher and lower tool rental charges automatically result from the greater and lesser rates as they occur in the progression, which in turn are peculiarly fitted to the expressions of drilling costs as determined by the size, cost, and capacity, of correspondingly heavy and light duty outfits.

A natural inquiry is how the choice of drilling equipment may be affected by the cost as expressed by accumulations of tool rental. In this connection, cost is not necessarily represented by money or wealth. Henry Ford contends that "wealth is the use value of things"—and it is this contention that we believe to be applicable to the choice of drilling equipment. As mentioned before, ultimate cost is the foundation of tool rental, and the selection of drilling equipment should be affected most subjectively by the total rather than the partial cost. Therefore, the cost of a $150,000 rotary outfit actually approaches $200,000, and the operator who contemplates its purchase must not overlook its total evaluation in terms of the work to be done. The work to be done can be estimated most satisfactorily in terms of work units. An analysis of future tool rental calculations then will show the expected future economic status of the purchase.

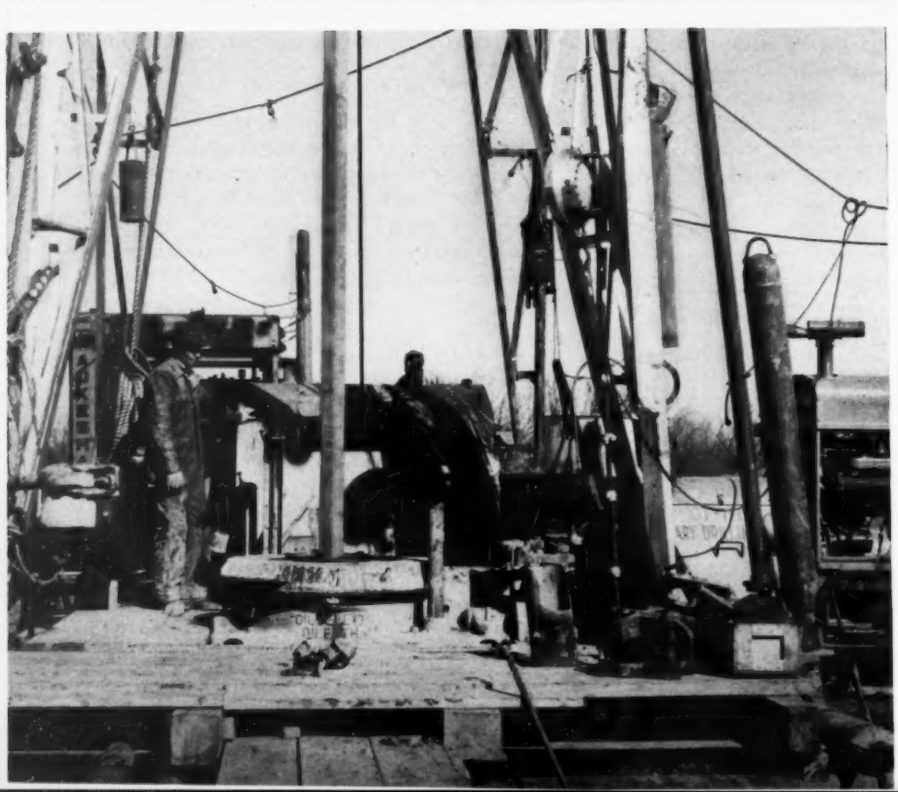
Acceptance by the industry of certain standards of drilling equipment performance rating could provide the superstructure upon which could be built an acknowledged schedule of drilling equipment values. From this, both small and larger operators would be able to determine their course with the same technical yardstick of combined experience. One of the critical weaknesses of such a scheme is the competitive nature of the business. However, professional as well as industrial competition recognizes the fundamental value of accumulated experience. Industry welcomes standardization of policies in order to obtain the benefits of more systematic self-regulation. Actually, then, in the final analysis, the cost of drilling equipment may be said to be based upon the factors which influenced its choice.

Mechanical Rigs Featuring Extreme Portability

Franks Manufacturing truck mounted rig in over-the-road position: eliminates individual well derrick, being equipped with a built-in, open-faced derrick which is mechanically raised and lowered. Blocks are strung, tongs hung, and suction and discharge manifolds of the pumps are permanently hooked up whether drilling or moving. Equipped with friction clutches; all drives may be driven by one engine or both, compounded. Requires a three man crew and is capable of exploratory drilling to 5000 ft.



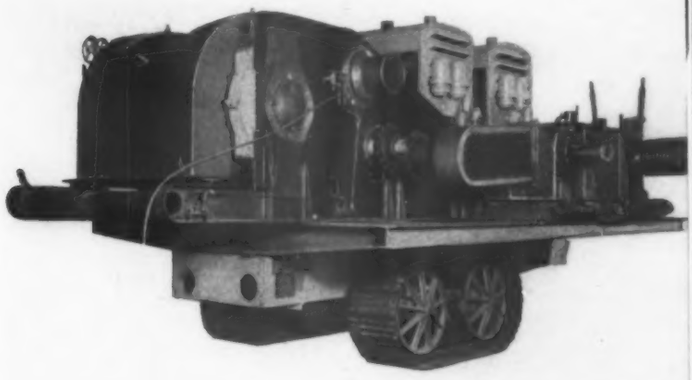
Cardwell double drum drawworks can be converted from rotary to cable tool operation in three or four hours on the derrick floor making it possible to drill with rotary and drill-in with cable tools. Friction clutch drums make it possible to lift cable tools or drill stem quickly when cave-ins occur, without stopping the spudding motion or rotary table. Available in three sizes capable of 7500 ft. with cable tools or 5000 ft. with rotary using 4½ in. drill pipe.



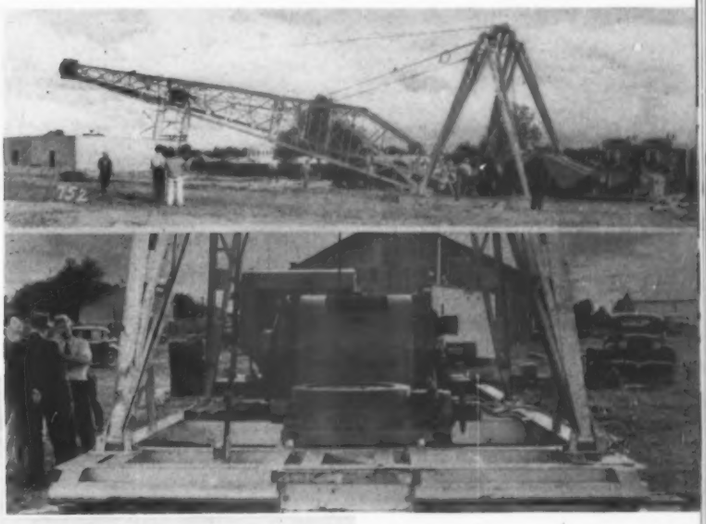
An "Oilwell" rotary drilling unit operating on butane. The drilling unit is in foreground and is driven by a Waukesha engine. The Universal hoisting unit is in the background and is driven by two Waukesha engines. The engines may be operated separately or compounded for driving the "Oilwell" power slush pump or the hoisting drum. The rig as shown is drilling a 3000 ft. well in North Texas.

Bucyrus-Erie portable rig with six-cylinder, natural gas engine developing 128 hp. at 1800 rpm. In high gear this equipment is capable of hoisting 1200 lbs. from 3000 ft. in eight minutes. The collapsible derrick is 54 ft. long and will handle up to 50,000 lbs. The rig has a dual braking system, free-wheeling and instantaneous reverse.

Portable Rig Company's 3000-4000 ft. completely truck mounted rig: fully unitized it consists of two gas, gasoline or Diesel engines compounded. The slush pump is driven through a power take-off from the truck engine.



Portable Rig's unitized rig with drawworks, dual engine drive, engines and subframe mounted on an Athey Caterpillar Trak-Tractor type wagon which serves as a foundation on location. Slush pumps are mounted on another smaller wagon or on skids.



Lee C. Moore cantilever jackknife drilling mast mounted on a skid type base in conjunction with a Portable Rig Co. drilling rig. Eighty-seven feet in height, this derrick will carry up to 415,000 lbs. The base may be folded for highway travel and is equipped with regulation height substructures. In the upper picture the derrick is just raising off the ground. When erect it is self-supporting and does not require guy lines.

Portable Rig Company's unitized rig for 6,000 ft. drilling, mounted on two levels; drawworks at derrick height with pumps, engines and dual drive on ground level. The drawworks and dual drive are equipped with forced feed lubrication, hydraulically operated cone type clutches on rotary and drum shafts. The rig is equipped with four forward and three reverse speeds on drum and rotary with an additional fifth speed on the drum to provide fast hoisting speed for light loads.

WORLD OIL PRODUCTION

Figures in U. S. barrels of 42 gal.—Conversion ratios used are weighted averages for individual countries.

U. S. BARRELS METRIC TONS

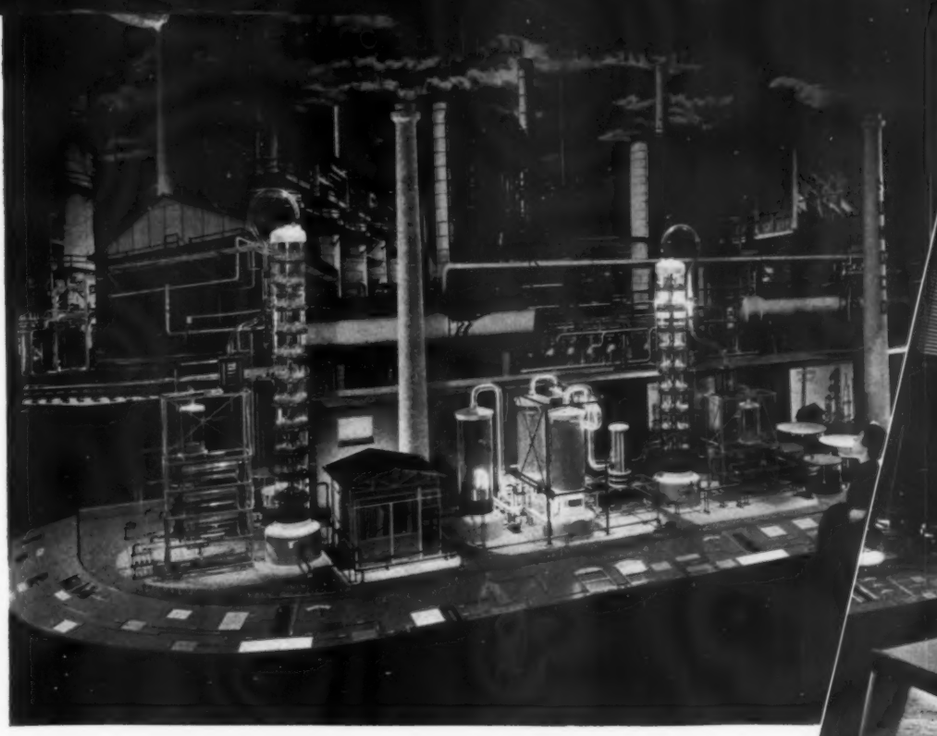
	April 1941 Preliminary	April 1940	Jan.-April 1941	Jan.-April 1940	April 1941 Preliminary	April 1940	Jan.-April 1941	Jan.-April 1940
United States	111,805,500	116,046,000	436,062,400	457,930,500	15,127,249	15,700,987	58,999,106	61,957,906
Soviet Union	18,300,000	17,896,000	73,300,000	72,010,191	2,510,288	2,436,780	10,054,867	9,836,520
Venezuela	16,904,850	16,495,995	63,182,234	61,189,758	2,510,000	2,449,294	9,381,178	9,085,339
Iran	6,500,000	6,507,180	25,747,200	26,117,651	848,674	863,190	3,384,600	3,464,588
Netherland India: Sumatra	3,300,000	3,428,880	13,295,000	13,491,994	422,481	438,960	1,700,144	1,727,286
Borneo	1,000,000	1,063,890	4,170,000	4,317,359	128,024	136,290	533,875	552,814
Java	500,000	537,720	2,087,600	2,168,656	64,012	68,820	267,637	277,620
Molucca and Other	55,000	67,740	233,800	243,316	7,041	8,670	30,039	31,148
Rumania	2,913,125	4,422,721	11,578,125	15,624,071	395,000	599,691	1,570,000	2,118,518
Mexico	2,880,000	3,180,000	11,851,000	12,962,067	422,907	466,960	1,740,233	1,903,750
Iraq	975,000	2,578,020	3,925,000	10,321,585	130,330	344,670	524,662	1,380,791
Colombia	1,700,000	2,229,000	6,837,000	8,935,890	237,099	310,878	953,556	1,246,286
Trinidad	1,725,000	1,580,940	6,975,000	6,380,814	242,616	222,360	981,013	897,427
Argentine	1,795,000	1,616,171	7,161,000	6,505,038	255,698	230,223	1,020,085	926,642
Peru	975,000	1,097,400	3,950,000	4,463,238	128,712	145,200	521,450	590,531
Bahrein	561,000	579,078	2,386,000	2,428,554	76,555	79,022	325,598	331,553
Burma	650,000	666,810	2,605,200	2,652,409	89,779	91,980	359,176	365,083
Canada	825,000	634,869	3,214,730	2,347,445	104,988	80,792	408,666	298,732
Brunei	464,751	471,540	1,858,562	1,904,554	62,000	62,880	247,940	254,011
Great Germany: Old Reich	377,622	371,610	1,487,622	1,499,615	54,000	53,940	212,730	216,700
Ostmark	58,359	61,230	233,959	238,892	8,700	9,780	34,878	37,986
Slovakia and Moravia	9,502	9,780	38,102	39,477	1,400	1,470	5,666	5,929
Poland	320,000	320,790	1,261,400	1,293,663	43,132	43,050	170,020	173,602
Japan	210,900	216,960	846,757	877,137	30,000	31,020	120,449	125,352
British India	181,000	180,090	731,688	747,972	25,000	24,870	101,061	103,287
Ecuador	116,094	208,513	440,858	812,656	15,305	27,490	58,120	107,138
Saudi Arabia	467,900	476,359	1,869,700	1,897,639	63,400	64,531	253,343	257,067
Sarawak	101,720	108,330	413,160	438,279	13,000	13,920	52,740	56,417
Egypt	625,000	460,000	2,525,000	1,803,367	89,260	65,695	360,609	257,549
Italian Empire: Albania	133,440	119,250	533,440	473,249	20,000	17,790	79,950	70,637
Italy	3,864	5,000	15,764	23,150	480	620	1,964	2,870
France	39,922	41,100	154,922	165,888	5,600	5,760	21,729	23,232
Hungary	178,392	120,000	708,150	420,000	24,000	16,140	95,270	56,490
Bolivia	10,802	8,310	41,906	33,428	1,400	960	5,431	3,872
Other Countries	47,800	48,150	191,200	192,858	6,800	6,780	27,200	27,286
WORLD TOTAL	176,711,543	183,856,166	691,913,879	722,952,360	24,164,930	25,121,463	94,604,985	98,771,959

Official Crude Oil Production Figures from 1938 to 1940

Daily Averages

	Bbl.		Metric Tons		Bbl.			Metric Tons		
	Jan.-April 1941	Jan.-April 1940	Jan.-April 1941	Jan.-April 1940	1940	1939	1938	1940	1939	1938
United States	3,633,853	3,784,549	491,659	512,048	1,351,849,500	1,264,962,000	1,214,355,000	182,904,869	171,152,192	164,346,325
Soviet Union	610,833	595,125	83,790	81,293	216,909,066	216,727,024	206,192,000	29,702,277	29,530,168	28,859,000
Venezuela	526,518	505,700	78,176	75,085	184,761,241	205,783,650	188,429,050	27,432,998	30,533,706	27,845,286
Iran	214,560	251,848	28,205	28,632	79,151,675	78,151,332	78,320,840	10,443,546	10,367,117	10,358,495
Netherland India: Sumatra	110,791	111,505	14,167	14,275	40,685,226	41,557,013	34,538,128	5,208,709	5,320,320	4,662,836
Borneo	34,750	35,680	4,448	4,568	14,006,279	13,125,425	12,812,383	1,793,148	1,680,377	1,719,783
Java	17,396	17,922	2,230	2,294	6,557,295	6,568,714	6,955,283	839,495	842,237	933,595
Molucca and Other	1,948	2,010	250	257	762,674	836,144	607,622	97,641	107,047	81,560
Rumania	96,484	129,124	13,083	17,508	42,885,625	46,020,000	48,366,000	5,815,000	6,240,000	6,603,000
Mexico	98,758	107,122	14,501	15,733	40,000,000	39,428,141	38,505,824	5,873,715	5,794,035	5,716,423
Iraq	32,708	85,302	4,372	11,411	24,225,007	30,791,132	32,404,000	3,238,878	4,115,845	4,345,000
Colombia	56,975	73,850	7,946	10,299	25,592,890	22,036,613	21,581,588	3,569,434	3,067,568	3,007,935
Trinidad	58,125	52,734	8,175	7,416	20,218,568	19,270,256	17,736,176	2,842,918	2,710,515	2,472,943
Argentine	59,675	53,760	8,500	7,658	20,609,160	18,738,003	17,076,237	2,935,777	2,657,232	2,432,857
Peru	32,916	36,886	4,345	4,880	12,985,284	13,587,906	15,908,279	1,716,195	1,798,557	9,099,885
Bahrein	19,883	20,070	2,713	2,740	7,096,141	7,588,554	8,297,998	968,502	1,045,391	1,130,734
Burma	21,710	21,920	2,993	3,017	7,978,969	7,872,981	7,499,498	1,098,184	1,087,424	1,039,960
Canada	26,789	19,400	3,405	2,468	8,718,053	7,837,503	6,965,457	1,109,440	997,487	879,921
Brunei	15,488	15,740	2,066	2,099	5,729,374	5,767,227	5,387,214	764,006	768,320	707,123
Great Germany: Old Reich	12,396	12,393	1,772	1,790	4,543,954	4,487,491	3,850,044	653,590	647,337	552,074
Ostmark	1,949	1,974	290	313	718,494	693,247	370,038	114,045	109,904	63,468
Slovakia and Moravia	318	326	47	49	118,775	119,380	132,005	17,836	18,103	19,282
Poland	10,511	10,691	1,416	1,434	3,891,456	3,898,044	3,828,438	521,984	522,874	504,678
Japan	7,056	7,249	1,003	1,035	2,638,644	2,652,930	2,511,184	376,657	379,161	356,328
British India	6,097	6,214	842	853	2,249,835	2,332,467	2,330,209	310,596	322,160	322,125
Ecuador	3,673	6,716	484	885	2,349,015	2,312,118	2,257,278	309,686	306,824	319,877
Saudi Arabia	15,580	15,682	2,111	2,124	5,364,610	3,933,904	495,135	726,785	536,366	66,683
Sarawak	3,443	3,625	439	466	1,317,185	1,329,645	1,624,882	168,475	171,322	200,126
Egypt	21,041	14,903	3,005	2,128	6,053,367	4,603,797	1,561,231	864,514	657,570	223,058
Italian Empire: Albania	4,445	3,911	666	583	1,497,124	1,393,727	437,597	224,199	208,279	65,313
Italy	131	191	16	23	57,350	91,330	106,083	7,110	11,346	13,178
France	1,257	1,370	181	192	496,420	500,815	516,240	69,578	70,478	72,106
Hungary	5,901	3,471	810	466	1,755,000	815,248	330,829	236,025	109,896	42,798
Bolivia	349	276	45	32	110,484	100,885	106,620	14,249	11,998	13,262
Other Countries	1,593	1,593	226	225	579,997	578,036	243,000	82,779	82,300	34,080
WORLD TOTAL	5,765,948	5,974,813	788,374	816,297	2,144,463,737	2,076,492,682	1,982,639,390	293,052,840	283,981,456	279,111,097

Detailed monthly reports were published in February, 1941 issue.



Pew Presents Petroleum Exhibit to Franklin Institute

On May 8, with appropriate ceremonies, an important addition to the industrial exhibits of the Franklin Institute, Philadelphia, had its first public presentation. At that time, J. Howard Pew, president of Sun Oil Company, conveyed to the Institute for permanent display elaborate working models illustrating in full detail the production and refining of petroleum. Practical oil men who composed most of the gallery at the first demonstration agreed that the models provided the most realistic and instructive showing of oil recovery and processing that they ever had seen.

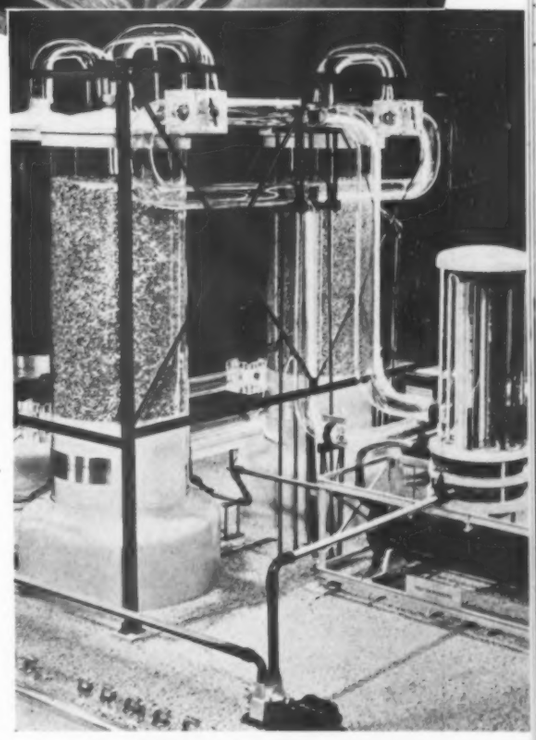
Dominating feature of the display is the miniature refinery consisting of three units shown against a huge photomural which gives a visitor the impression that he actually is looking at a great refining plant. The three sections of the exhibit include a distillation unit, a catalytic cracking unit and a mercury vapor lubricating oil unit. All vessels and pipe are of glass and the fluids passing through them are accurately tinted so that it is easy to follow their course and to understand the various processes and the results of their operation. In the lubricating unit real oil is used.

The refinery model is built to a scale in which one inch represents a foot. It includes a pipe still, a 12-plate fractionating tower, eight and one-half feet high, two catalytic cracking cases filled with actual catalyst, heat exchangers, condensers, storage tanks, gas separators, vaporizer and twenty-five model centrifugal pumps in motion to simulate the pumping of the liquids to various parts of the plant. The lubricating oil unit consists of a mercury boiler, a vacuum fractionating tower, a multistage steam injector pumps and storage tanks.

The working mechanism for the model is placed beneath the supporting platform. Among other equipment it includes ten motors of one-quarter horse power to drive the eighteen water pumps that propel the various liquids through the model, twenty-five small motors to drive the centrifugal pumps, eleven transformers of 3,000 to 9,000 volts to operate the neon and argon lights used to illuminate the cracking cycles, a thousand feet of copper tubing and a number of copper storage tanks.

The oil field model shows a derrick with full rotary drilling equipment including mud pumps in action showing mud flowing through the pumps from the mud pits to the swivel and returning by the flume to the mud settling pits. Other sections of this exhibit show a flowing well with miniature Christmas Tree and a pumping well in which crude is moved from the oil sand to gas and water separators and thence to field storage tanks.

Design and construction of the exhibit occupied a year's time, cost $30,000, and was carried out under the guidance of Sun Oil Company officials and engineers by the Franklin Institute and mechanics in the Institute's employ.



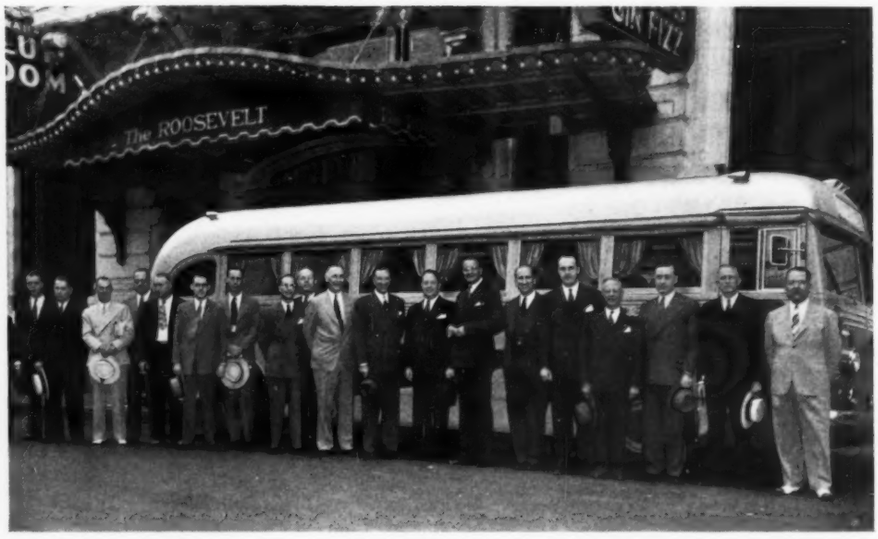
All-glass model of an oilfield and refinery, including a catalytic cracking unit, presented by Sun Oil Company to the Franklin Institute.

Foreign Oil Legion

L. J. Van Dijk and E. R. Parr of the engineering and drilling staff of Caribbean Petroleum Company, Venezuela, have been spending several weeks on a tour of Mid-Continent and California oil fields.

Emile Soubry, representative of the British Petroleum Board and chairman of the Anglo-American Oil Company, (Jersey Standard affiliate) arrived in New York aboard the Dixie Clipper from Lisbon on May 12 in company with Vincent Illing, professor of oil technology of the School of Mines of London University. Both oil experts are expected to make a study of U. S. and South American oil supplies for Britain with particular reference to high octane aviation spirits.

E. E. Soubry



Standard Oil Company of New Jersey, Sales Officials traveling in a special bus, have been making an extensive tour of the Southeastern United States. Left to right: H. M. Caldwell, E. A. Barielle, E. J. Landry, H. W. Chapin, A. J. Rogers, F. G. Didier, J. V. Leitch, A. C. Fischofer, D. W. Spurlock, P. J. Ward, R. T. Haslam, T. M. Gordon, J. E. Skehan. A. A. Lacazette, J. A. Miller, H. C. Ferrell, S. E. Drummond, S. S. Morris, V. W. Kleinpeter.

Dr. Enrique Jorge Aguerrevere, formerly Minister of Public Works in the cabinet of Gen. Lopez Contreras, now holds the portfolio of Minister of Fomento in the recently announced cabinet of Gen. Medina Angarita, president of Venezuela. The appointment was announced on May 6th following the inauguration of Gen. Medina on the 5th.

North American engineers, industrialists and economists, being entertained in Montevideo by A. N. C. P.

(C) *Cosmo-Silco*

Lloyd G. Smith, general manager of the Lago Oil & Transport Company (SONJ) at Aruba, who sailed from New York on May 16th aboard the ss. Santa Paula.

Yerzy Morgenstern, director of the Morgenstern Oil Company of Poland, arrived in San Francisco from Manilla on May 21st. Mr. Morgenstern was carrying on operations of his company, one of the largest independents in Poland, when the war and subsequent partition of Poland occurred. The company's operations centered in that part of Poland occupied by Russia and Mr. Morgenstern resided in Lwow under Soviet rule for just over a year after the war in Poland had come to an end. He had a unique opportunity to witness the transportation arrangements for the shipment of oil supplies from Russia and Roumania to Germany.

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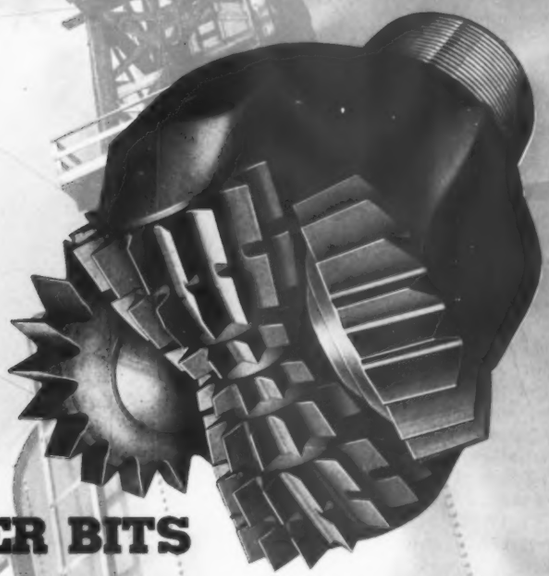

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WORLD PETROLEUM ABSTRACTS

Summaries of the Most Important Articles as Published in the Oil Press of the World Dealing with Technical and Economic Aspects of the Petroleum Industry — Edited by Dr. O. W. Willcox.

DRILLING

Improvement in Plastering Properties of Muds—H. T. Byck and J. W. Freeland, in OIL WEEKLY, vol. 100 (1941) No. 9, pp. 26; 30; 32.

When a drilling mud is contaminated with salts from the brines encountered in the well it is very apt to suffer a loss of viscosity due to flocculation of its colloidal constituents. This in turn unfavorably affects the ability of the mud to plaster the walls of the well and there will be a loss of water if not of mud by filtration into the surrounding formations. When flocculation is due to salt water intrusion only a little help can be had by the use of more bentonite.

In this paper some experimental work is reported which shows the beneficial action of Irish moss or sodium alginate in such cases. Commercial Irish moss without further purification or concentration can be dissolved in hot or cold water to form a highly viscous liquid which is not precipitated by acids or calcium salts. Addition of from 0.2 to 0.6 percent (on weight of the mud) of this protective agent is sufficient for optimum correction of the condition induced by intruding salt water. The Irish moss is more or less subject to fermentation, but this may be minimized by addition of pyrophosphate or quebrocho soda. Much the same applies to sodium alginate.

An advantage of this system is that muds may, in case of necessity, be made with sea water. It also permits advantageous use of materials, such as slurries of oyster shells, which ordinarily could not be used.

Cost of Inefficient Drilling—W. L. De Arman, in DRILLING, vol. 2 (1941) No. 5, pp. 19; 36.

Experience in the East Texas field, now in its eleventh year, is cited to show that there is a real distinction between the first cost and the real cost of drilling an oil well; sooner or later the pumps will tell whether or not the hole was efficiently drilled. This experience shows that those operators who paid for "cheap" drilling have not obtained a bargain.

In the East Texas field there are now some 6,328 wells on the pump. A large number of work-over jobs are being done. From 60 to 70 percent of production time lost on pumping wells is due to failure of underground equipment; a major cause of such failures is a badly drilled hole. Variations from vertical of more than 20 degrees are not uncommon, although drilling conditions are generally good in this region. Aside from crooked holes, casing improperly landed or run, penetration of the sand without regard to the water level, and water sands not sealed off have caused the abandonment of many wells which otherwise could have been kept on production. Pulling costs on similarly equipped wells vary according to the degree to which the wells are off vertical and range between $150 to $750 a year. Even the final value of an East Texas well — the salvage value — is determined largely by the manner of digging; casing recovery varies from 3,200 to a few hundred feet.

CHEMISTRY

Methods for Clarifying Oxidized or Used Mineral Oils and for the Determination of Sludge—G. O. Abrey before division of PETROLEUM CHEMISTRY, AMERICAN CHEMICAL SOCIETY, St. Louis meeting, April, 1941.

A laboratory apparatus and a method of use are described for obtaining from used or oxidized mineral oils a sample of clarified oil free of sludge undissolved at the clarification temperature. The clarifying or filter medium is two Seitz S-3 type asbestos disks through which the oil is forced by gas pressure applied while maintaining the oil and the apparatus containing it at the desired temperature. The applications of the method in the study of the changes occurring in used or otherwise oxidized oils are indicated.

The construction and method of use of an apparatus for mineral oil sludge determination are described. The apparatus is of such design that an open-bottom metal cup is drawn down and sealed against a supported Seitz S-3 type asbestos disk which serves as

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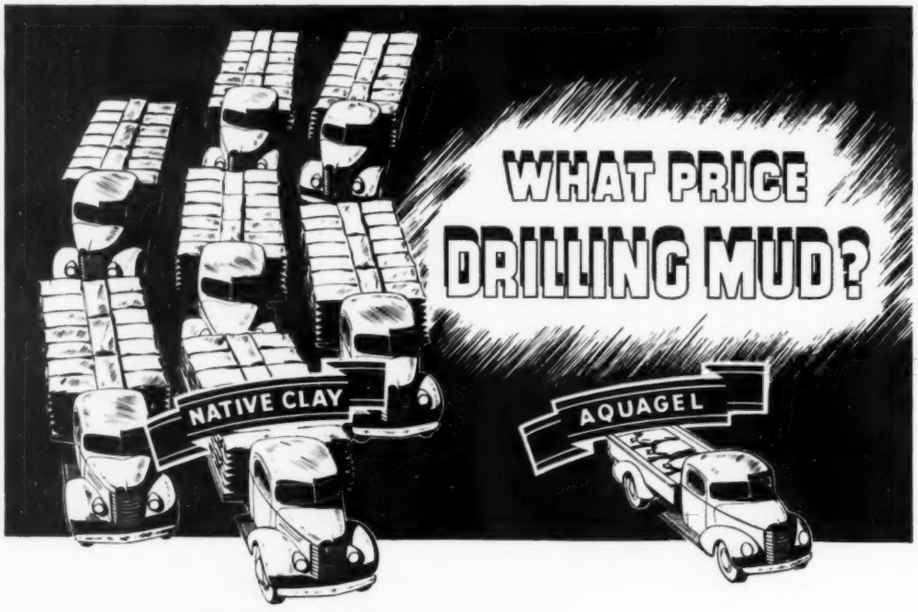

IN A 5000-FOOT WELL AS MANY AS 650 SACKS OF SOME NATIVE CLAY ARE USED IN FILTER CAKE ALONE; WITH AN AQUAGEL-WATER MUD, ONLY 18 SACKS!

Operators with an eye to economy as well as fewer drilling troubles use an AQUAGEL-water mud in place of ordinary native clay mud in wells which do not require weighted mud. On the basis of economy alone the saving is readily apparent by considering two open holes each 12¼" diameter and 5000' deep, one drilled with an ordinary native clay mud and the other with an AQUAGEL-water mud.

Some ordinary native clay muds deposit a filter cake ¾" thick. The total amount of such filter cake in a 5000' well will occupy a volume of 941 cubic feet made up of 45% by volume of solids (420 cubic feet of solids). At 2.5 specific gravity these solids will weigh 65,000 pounds and will use up 650 one-hundred-pound sacks of native clay for the filter cake alone.

AQUAGEL-water mud deposits a filter cake about ⅛" thick. The total amount of this filter cake in a 5000' well will occupy a volume of 165 cubic feet made up of 7% solids by volume (12 cubic feet of solids). At 2.5 specific gravity the weight of these solids will be 1800 pounds and will use up only 18 sacks of AQUAGEL for the filter cake.

Using those two muds as an example the tonnage required to build the filter cake alone on the walls of the hole is 35 times more in the case of the native mud than the AQUAGEL required. This extra unnecessary cake thickness is not only expensive but detrimental to drilling operations and may cause stuck tools.

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This well using an AQUAGEL-Water Mud has only 1800 lbs. of filter cake on the walls of the hole which is not only economical but very advantageous to drilling operations.

This well using an ordinary native clay has 65,000 lbs. of filter cake on the walls of the hole which is not only expensive but detrimental.

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the filter medium. This Seitz disk is in effect a preformed asbestos mat. The advantages and limitations of the method are mentioned. Modified uses of the apparatus in other ways than suction filtration of diluted oils are suggested.

California Petroleum Acids—Wm. O. Ney, W. A. Quebedeaux and H. L. Lochte, before Division of Petroleum Chemistry, AMERICAN CHEMICAL SOCIETY, St. Louis meeting, April, 1941.

In continuation of work on petroleum acids from California straight-run gasoline 8 additional aliphatic and 1-naphthenic acid have been isolated and identified from the methyl esters through careful fractionation.

2-Methyl, 3-methylpentanoic, *n*-hexanoic, 2-methyl, 3-methyl, 4-methyl, 5-methylhexanoic, and *n*-heptanoic acids, six of these for the first time from petroleum, were identified, as was cyclopentane carboxylic acid which had been found previously in European petroleum acids.

Oxidation of Lubricating Oils—M. R. Fenske and others, in INDUSTRIAL ENGINEERING CHEMISTRY, Analytical Edition, vol. 13 (1941), No. 1, pp. 51-60.

An apparatus and procedure are described which permit determination of rate of lubricating oil oxidation at temperatures usually between 130 deg. to 180 deg. Pure dry oxygen is circulated from the heated oil to a system of absorbers that absorb the oxidation products so that the purified oxygen can be recirculated. The volatile reaction products are found to include CO_2, CO, volatile acids and some volatile carbonyl compounds. The oxidized oil was examined for "dirtiness" including insolubles and "laquering substances," acidity and viscosity change.

Ninety to 100 per cent of the oxygen absorbed by various oils has been accounted for in the products determined. The chief product is water, which accounts for 40 to 60 per cent of the reacting oxygen. Soluble saponifiable materials represent another considerable portion, while carbon dioxide, carbon monoxide, volatile acids, fixed acids, and precipitable products account for the remainder.

The analysis of insoluble materials produced by laboratory and engine oxidation indicates these to be relatively highly oxygenated materials (14 to 24 per cent oxygen) produced by polymerization or condensation of the oxidized oil. Molecular weights and elementary analyses suggest certain empirical formulas for the insoluble bodies.

The oxidation of several commercial light oils shows that rates of oxidation vary widely and that induction-type oxidation curves may be common. In general, these results show the widely different oxidation characteristics existing in oils, and that much of the oxidation mechanism remains to be understood before corrective measures are generally applicable.

Analytical Determination of Paraffin in Oils and Paraffin Stocks—Bruno K. Engel, in OEL UND KOHLE, vol. 37 (1941), No. 1, pp. 23-25.

For characterizing mineral oils and residues, distillates and especially lubricating oils, it is customary to state the paraffin content of these products. For this purpose the paraffin is precipitated from the sample by means of some liquid in which paraffin is not soluble, for instance alcohol-ether, acetone, dichloroethane or chloroform. The operation is conducted at a very low temperature. While reproducible results may be obtained with any of these solvents their use

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results in conflicting figures as to the paraffin content, due to the fact that these liquids have different selective solvent properties.

The author proposes another method based on a different viewpoint. Instead of depending solely on the gravimetric determination of the paraffin without regard to the condition in which the original material is left, he puts the latter in the foreground. That is, he decides beforehand what cold-point the deparaffined product (the liquid oil) should have, and then determines what must be the yield of liquid oil after removal of this amount of paraffin.

The method then is to treat 75 cc. of the asphalt-and resin-free oil with 225 cc. of standard gasoline (b.p. 60-95 deg. C., aniline point 58-62 deg. c.), cool to — 20 deg. c. and filter. The residue is well washed with the gasoline; filtrate and washings are combined, the gasoline is distilled off and the cold point of the residual oil and melting point of the paraffin are determined. The same procedure is repeated at — 30 deg. and — 40 deg. C. There are thus obtained three points for a graph of percent oil yield against cold point in degrees C. From such a curve, which may be extrapolated, it will be possible to determine how much oil of a certain cold point can be obtained, or what is the least amount of paraffin that must be separated to obtain a given cold point.

Isolation of Five New Bases from California Petroleum and Their Synthesis—Leslie M. Schenck and J. R. Bailey, before DIVISION OF PETROLEUM CHEMISTRY, AMERICAN CHEMICAL SOCIETY, St. Louis meeting, April, 1941.

The new bases presented in this paper include 2, 3, 4-trimethyl-8-i-propylquinoline, 2, 3-dimethyl-4, 8-diethylquinoline, 2, 3-dimethyl-4-ethyl-8-n-propylquinoline, 2, 3-dimethyl-benzo (h) quinoline, and 2, 4-dimethylbenzo (h) quinoline.

This contribution increases the quinoline type bases isolated in the Texas Laboratory to twenty-one. The dimethyl-benzoquinolines are the first representatives of this family of nitrogen compounds to be obtained from a natural source.

The laboratory technique employed in the isolation of the new compounds includes exhaustive fractional distillation, cumulative extraction, sulfiting and degassing, countercurrent extraction, and final purification through the crystallizing properties of their organic and inorganic acid salts. In all cases the structures assigned the bases have been confirmed by synthesis.

The Determination of the Heat of Combustion of Gasolines—W. H. Jones and C. E. Starr, Jr., before DIVISION OF PETROLEUM CHEMISTRY, AMERICAN CHEMICAL SOCIETY, St. Louis meeting, April, 1941.

The increasing importance of heat of combustion measurements in petroleum analytical work has made desirable the critical examination of the adiabatic bomb calorimeter method used for testing gasoline samples. Various errors may occur with samples of this nature, which are not encountered in less volatile liquid or solid samples.

It is shown that by rigid control of several factors, the usual accuracy of ±100 B.t.u. per pound may be improved so that ±30 B.t.u. per pound may be readily attained. In this connection results obtained on samples of pure *n*-heptane and on gasolines are described.

Improvement of Mixed Cresols for Inhibitor Purposes, and the Use of Mesitol as a Gum Inhibitor—I. Kennedy in JOURNAL INSTITUTE PETROLEUM, vol. 27 (1941), No. 207, pp. 15-18.

It has been observed that while phenol is an inhibitor of gum formation in cracked gasoline, its ortho and para alkyl substitution products are still more efficient. The problem of improving mixed cresols for inhibitor purposes is therefore the problem of increasing the number of ortho and para substituents in the cresol molecule.

That being the case, a natural supposition was that mesitol (2:4:6-trimethyl phenol) would be a very efficient inhibitor, as it has both the ortho and the para position substituted by methyl radicles. Mesitol was therefore prepared in the usual manner and its effect as a gum inhibitor compared with that of o-cresol by an accelerated oxidation test on an Iranian cracked gasoline. Result: mesitol has an efficiency six times that of o-cresol.

Quality Tests for Petroleum Solvent Naphthas—E. H. McArdle and E. L. Baldeschwieler before DIVISION OF PETROLEUM CHEMISTRY, AMERICAN CHEMICAL SOCIETY, St. Louis meeting, April, 1941.

Existing quality tests for petroleum solvent naphthas, including solvency, volatility, physical properties, and proximate composition, are catalogued and appraised. Data are presented graphically to show their interchangeability. Stressed is the critical importance of volatility, or average molecular weight, to the correct interpretation of any solvency test result. The standardized kauri-butanol method—recently criticized in several discussions of solvency—is demonstrated to serve adequately as a measure of solvent naphtha

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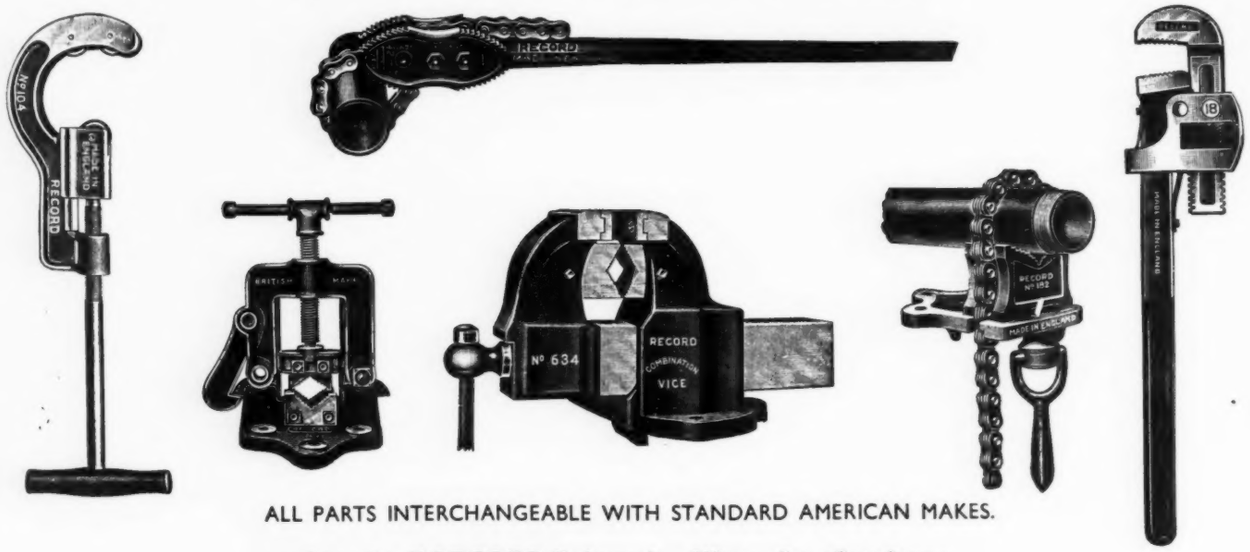

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performance. It is concluded that no additional solvency tests are needed, but that lacking is the development of a rapid, precise, and accurate method for determination of evaporation rate.

PHYSICS

Investigation on the Dipole Moment of Oils—R. Heinze, M. Marder, K. H. Doering and K. Blechstein, in OEL UND KOHLE, vol. 37 (1941), No. 1, pp. 8-23.

This investigation starts from the known fact that oils with high polarities have good lubricating properties. Since the dipole moment is a measure of polarity, the investigators devised a method and an apparatus for measuring it in the hope of connecting the dipole moment with the "oiliness" of oils from different sources.

The dipole moments of mineral oils are found to be mostly smaller than 0.4×10^{-18} centimeters $\times$ electrostatic units. This gives a direct demonstration of the electrocentric structure of the lubricating molecule. Aged and used mineral oils have a higher dipole moment than the original unused oil. On account of their strongly polar character oxygenated products and fatty acids increase the dipole moments of mineral oils with which they are mixed. Since such mixtures have better lubricating properties than the unmixed oil, it is concluded that dipole moment and oiliness are correlated. The exact extent of this correlation will have to be determined by further investigation.

As stated, the dipole moment of most oils is less than 0.4 unit on the authors' scale, but various added substances may raise it above 1. An excellent lubricant prepared from brown coal tar had a dipole moment of 1.2; evidently such an oil must have a structure different from that of a mineral oil lubricant, due perhaps to the presence of highly polar and oxygen-containing constituents.

The Distribution Law in Extraction with Selective Solvents—Hans Vogel in OEL UND KOHLE, vol. 36 (1940), No. 46, pp. 547-552.

The author restates the distribution law in the following terms:

"During the separation, so much extract passes into the extract layer and so much solvent into the raffinate layer, that after establishment of equilibrium the concentration by weight of the extract in the extract layer is equal to the concentration by weight of the solvent in the raffinate layer."

The fundamental formula is:

$$C(b, 0) - c\ (b, u) = 1$$

wherein b is the weight of the solvent, o the weight of the raffinate layer, u the weight of the extract layer, $c(b, u)$, the concentration by weight of the solvent in u, and $c\ (b, o)$ the concentration by weight of the solvent in o. In other words this fundamental equation says:

"The sum of the concentrations by weight in the solvent-poor layer and in the solvent-rich layer at equilibrium is unity."

Or stated in another way it means:

"The sum of the concentration by weight of the insoluble portion (raffinate) of the material to be extracted in the solvent-poor layer and the concentration by weight of the dissolved portion (extract) in the solvent-rich layer at equilibrium is unity."

This distribution law is valid only for liquids which can be mixed without thermal change, formation of new molecules, or dissociations or associations.

On the basis of these principles, which are attested by much experimental data, there has been worked out an experimental method for determining the constitution of mineral oils by extraction with selective solvents. The method does not require that the solvent be distilled off; it is only necessary to determine the weights and the specific volumes of oil, solvent, extract layer and raffinate layer. From this data conclusions may be drawn as to the extract content of the extract layer and raffinate content of the raffinate layer.

Temperature Coefficient of Density and Refractive Index for Hydrocarbons—M. R. Lipkin and S. S. Kurz, Jr., before DIVISION OF PETROLEUM CHEMISTRY, AMERICAN CHEMICAL SOCIETY, St. Louis meeting, April, 1941.

Using the equation

$$d_4^t = d_4^{20} + a\ (t - 20) + B\ (t - 20)^2$$

a single curve of a versus molecular weight and a single curve of B versus molecular weight has been found applicable to all types of hydrocarbons with very few exceptions. From these curves the tempera-

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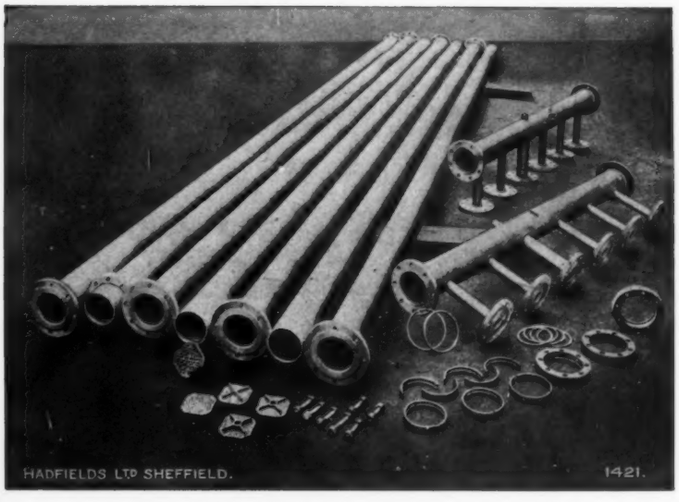

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ture coefficient of density can be predicted from the molecular weight within ±0.00002 gram per cc. per °C. or better. The only definite exceptions to this relation are benzene, pentaethyl benzene, and hexapropyl benzene which show coefficients 0.00010 gram per cc. per °C. higher than the predicted values.

This relation is more general than any previously published for predicting the temperature coefficient of density.

Since Ward and Kurtz have shown that for hydrocarbons

$$\Delta n = 0.60\ \Delta d$$

an accurate method of calculating density change also provides an accurate means of calculating change in refractive index.

USES

Piston Deposits, Ring Sticking, Varnishing and Ring Clogging—W. A. Gruse and C. J. Livingstone, in JOURNAL INSTITUTE PETROLEUM, vol. 26 (1940), No. 203, pp. 413-429.

The two basic chemical changes in lubricating oils that underlie the formation of engine deposits are (a) the thermal coking of the hydrocarbons under essentially non-oxidizing conditions, and (b) the oxidation of the hydrocarbons. The first is what occurs in the familiar carbon-residue test; the second is the change involved in the Sligh, Indiana, Underwood and the British Air Ministry tests.

The cause of ring-sticking has been obscured in a cloud of controversy, with opinion divided into two camps.

One adheres to the belief that ring-sticking tendency increases with the ease of oxidation of the oil (as indicated by laboratory oxidation tests), whilst the other believes that a volatile oil is best, ease of oxidation being relatively unimportant. The outstanding feature of the situation seems to be a large mass of contradictory experimental data. The authors believe this to be due chiefly to the fact that experimenters are using different types of engines under different operating conditions and that the very important mechanical details are being controlled to different extents. Each of the two opinions is undoubtedly sound, depending on the conditions under which it was deducted. Either type of oil is likely to cause or not to cause ring sticking, depending on the conditions.

From their very extensive experimental work the authors definitely connect ring-sticking with oil consumption.

When oil consumption was low, a naphthenic oil left the rings free, whilst a paraffinic oil produced sticking. When oil consumption, on the other hand, was high, the reverse was encountered: the naphthenic oil stuck the rings and the paraffinic left them free. They have thus established the point that control on previous experiments varied.

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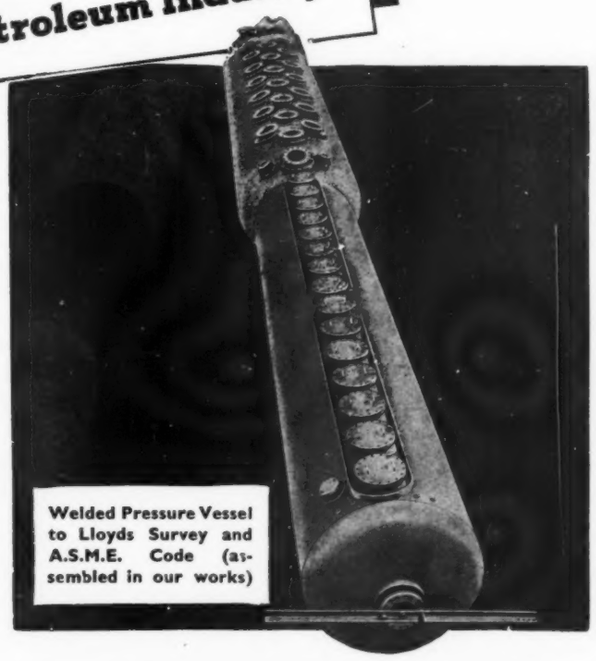

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(Continued from page 53)

25 to 50 percent is obtained. Pressure maintenance has also an advantage as compared to repressuring in that productive capacities of affected wells are sustained at high levels over far longer periods of time. This may be of greater importance to the country than increasing ultimate recoveries, because it may be necessary to meet war-time demands on short notice.

These are not arguments against repressuring, which is a valuable means of increasing reserves and productivity in depleted pools, but are intended rather as an evaluation of the two methods. The point emphasized here is that pressure maintenance should be used wherever possible.

As information becomes more widely disseminated, various efforts are made to increase efficiency of recovery. The work of the Oklahoma City Wilcox Zone Association which has been studying the application of secondary recovery to the Wilcox zone in the field, is an outstanding example. A bill is now before the Oklahoma legislature which if passed will authorize communization of the zone into units and allow production from each unit to be distributed to the various working and royalty interests in accordance with their estimated proportionate ownership, regardless of the particular well in the unit from which the production is obtained. Although this bill is confined to the Oklahoma City pool by certain of its provisions, it is the most advanced step yet contemplated by any state, and if passed unquestionably will be a guide post for general legislation.

The K. M. A. Pool in North Texas is probably the outstanding example of cooperative action in pressure maintenance to date. Over 1500 producing wells, with an allocated area of 27,700 acres, are in this large field, which is not as yet fully developed. Input wells, 179 in number, are scattered throughout the entire area. About 150 different operators are involved. Gas injection as a cooperative undertaking has been carried on for about 14 months, and at present about 25 percent of total produced gas is being returned to the reservoir. This percentage is being increased from time to time as high-pressure lines are extended and as new wells are connected. Flow schedules are being worked out to prevent overloading the various compressor plants. A marked decrease in the rate of pressure drop has been noted.

Of special interest to the drilling contractor is the fact that pressure maintenance will not encourage drilling on wider spacing than is now employed. Prompt application of the process would make drilling of many locations not now considered commercial a very profitable undertaking, so drilling will be encouraged in certain areas.

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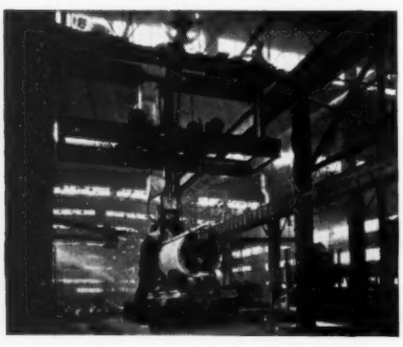

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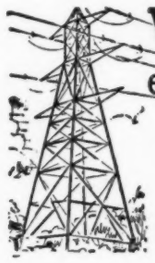

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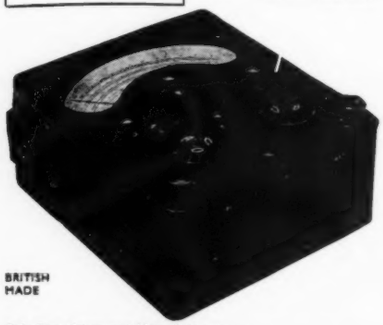

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